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THE FEBRUARY SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

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THE SCIENTIFIC MONTHLY

FEBRUARY, 1932

AN ANT HILL

By Professor E. A. ANDREWS

THE JOHNS HOPKINS UNIVERSITY

In the summertime everywhere about our dwellings little ants are busy digging into the earth to make their homes, and throwing up piles of earth as mere culm of no use to themselves or to others; but it is not such little ant hills that interest us now; rather the mounds found far from our habitation, ant hills of large dimensions, knee high or even waist high, whatever that changing yard stick may be.

Numbers, Size, Distribution of Ant Hills

Of the many sorts of large durable hills built by ants, those of Europe are the best known, but here in the United States are many of equal importance, such as those of the ant *Formica exsectoides F.*, that so resemble the European *Formica exsecta.*

Formica exsectoides F. became famous from the researches of the Reverend H. McCook, who, in August, 1876, camped out in "The Ant City," near Hollidaysburg, Pennsylvania, where this ant, the local "pismire," had built up a settlement of some 1,700 hills. That this assemblage may well be called a city is evident from the facts that each hill harbors thousands of ants and the hills were not sparsely scattered, as with our rural dwellings, but found by McCook built many to the acre: thus he records 33 to one acre, 25 to another, an average of 20 to the acre near Hollidaysburg, while at the crossroads known as Warrior's Mark, the ant hills stood 55 on two acres and 74 on two acres and a half, yet the average was 30 to the acre; while a third populous region, Pine Hills, revealed thirty acres settled at the rate of some 59 to the acre.

These ant hills were of all sizes but some measured from 10 to 12 feet in circumference and from 2 to 3 feet in height; one was 12 feet across and 30 feet around; another 15 across and 37 around; the largest of all three feet and a half in height and 58 feet in circumference, and this stood upon the site of some former charcoal burner's hearth.

Nearly fifty years passed, and in 1924 this ant city near Hollidaysburg still continued, but greatly fallen from its former magnificence. Competition had become too keen; bipeds escaping from Altoona by the trolley that meets all the trains had set up their villas where the ants had shown the way; over some 20 acres but 50 occupied and 10 deserted ant hills remained to represent the 1,700 mounds in 1876. Still the station of the trolley there was labeled "Ant Hills"—and let us hope that term may remain after all the ant hills are crowded out by human occupation of that region.

This same ant builds its hills in Nova Scotia, Ontario, New England, New York, Carolina, Georgia, Wisconsin, Illinois; while in Maryland large settlements have been found in the mountains

of the western counties and near the boundaries of the coastal and piedmont regions in Prince George's, Montgomery and Baltimore counties.

Ant Hills in Maryland

While one may come upon a single mound in some glade or abandoned field, more often where there is one there are several to be found scattered in constellations, with often a larger central mound and surrounding or nearby satellites that seem to have arisen from the process of colony formation or swarming resorted to by this ant in gradually extending its possession of a region.

Observations of mounds near Baltimore show that such an ant city is subject to waxing and waning, to extensions and retractions, of its boundaries, aside from direct interference from man, who, as a summer dweller in the woods, has no respect for the ant hills that preceded his bungalow.

Near Lutherville and Timonium, as far back as 1850, there were, according to the statement of Professor Philip Uhler, some very large mounds in a region of several hundred acres that had been deserted and unused for years after the exhaustion of old open diggings for bog-iron ore that left deep and lasting scars in the clay and gravel. With the growth of trees through fifty years the old mounds disappeared, all but mere circular ruins in the high timber, while many new mounds appeared in younger growths nearby. Thus, in 1905, 157 mounds formed a sort of town by themselves and 27 others an outlying village, inhabited by friendly ants that when carried from one settlement to the other acted and were received as if at home. These mounds were from 1 to 8 feet in diameter and from a third to two feet in height, but already some 67 were deserted mounds no longer inhabited. A second census taken in 1920 yielded 193 mounds, of which 10 or so were deserted. The greatest change, however, was in actual location of the mounds. The center of population had shifted. Many new mounds had arisen where there had been none and some of the old mounds had been deserted. At least 25 mounds remained active all the fifteen years. Mounds deserted in 1905 remained abandoned, and yet faint indications of them might still be traced in many cases. The village of 27 mounds grew in 15 years to contain 84 mounds.

Seeking reasons for the passing of mounds and the upspringing of others and the shifting of locations in certain parts of the settlement, we found that each mound may have its strongly marked individuality; a certain mound gained in fifteen years but two inches in height and only five in diameter, remaining of the same appearance, while another hill added to its two feet of height eight inches more, and to its diameter of five feet, three feet more. Six mounds showed an average increase of half a foot in height and two feet in diameter. The surface and color of mounds also was diverse but was evidently dependent upon the local soil and adjacent vegetation. But aside from such differences there were apparent reasons why whole series of mounds failed and others succeeded. Deserted mounds were often in shaded areas and successful mounds in sunny exposures. Mapping of mounds and trees in 1920—26 showed of 118 mounds 12 per cent. in the shade and 88 per cent. in the sunshine; in the shade 4 were occupied and 11 deserted; in the sun 94 were occupied and 9 deserted. Again, of the 67 mounds added to the settlement in 4 years, 18 per cent. were in the shade, and 80 per cent. in the sun; of these in the shade 3 only were occupied and 9 deserted; while of those in the sun 51 were occupied and 4 deserted. Sunshine

and shadow are correlated with success and failure of these ant hills as useful habitations.

In these four years this portion of ant town had spread rapidly as western suburbs arising upon bare mine dump amidst sparse weeds and brambles, the vanguard of sapling black locust, oak and tulip that followed along after the mounds and seemed to threaten their continuance as they grew to be large trees.

In harmony with this we find such mounds in mining regions, mountain slopes, abandoned fields, glades and windfalls in the denser woods. On the one hand, too successful forestation and on the other field cultivation are inimical to the success of these builders of ant hills.

The basis for this dependence of the mound upon "place in the sun" will be better understood after we have considered the mound in connection with the two fundamental activities of ants feeding and breeding. Each mound is not a mere accidental accumulation of a ton or so of earth resulting from the mining operations of the ants, but it is a fabricated nest serving as the communal home into which the food is brought and in which all the young are produced and reared; it is the ants' home. Each mound is the property handed down from generation to generation in the family or social organization that inhabits it and is of kin to all the neighboring inhabitants of these communal houses.

Each hill is comparable to the nest of a hornet family and like that is roughly a conical structure gradually built up from small beginnings.

Form of the Ant Hill

The ant hill seems to aspire to a cone as ideal, as fine sand dumped from a cart or the sands of an hour-glass, and all these cases are alike in that particles are arranged dependent upon gravity and friction, but in the ant hill each particle has been placed by the efforts of an individual ant working independently of its fellows so that the resultant shape depends primarily upon these innumerable dumpings centered about the ideal cone axis. (Fig. 1.)

While the eye may exaggerate the steepness of these little mountains, direct measurements as well as the tracings of photographs show that there is a great diversity in slope and form in different hills, depending evidently in part upon the materials used in different places and greatly influenced by vegetation. Few come to a conical point, all are rounded or flattened with various curves. Continuing the side slopes toward a theoretical apex we find the angles made there vary from 100 degrees to 150 degrees, the average of 20 mounds being 123 degrees as measured east-west and 128 degrees as measured north-south. Fifteen other mounds had the like averages of 116 and 119 degrees.

Though some mounds are quite symmetrical with equal radii, the majority exhibit more or less asymmetry in that the base is not circular and the faces east, west, north and south not all equal. Thus the above averages were due to some mounds having a longer south face which increased the angle at the apex. Frequently the north face is not only shorter but noticeably steeper and the apex of the mound is nearer to the north limit of the mound. Along with this the north face is often less well kept up and more neglected by the ants and more prone to be overgrown by mosses. Thus we have to some extent American representatives of the famous "compass mounds" of the Alps that enable mountaineers lost in the fog to recover their compass directions by observation of ant hills that plainly show differences between south and north.

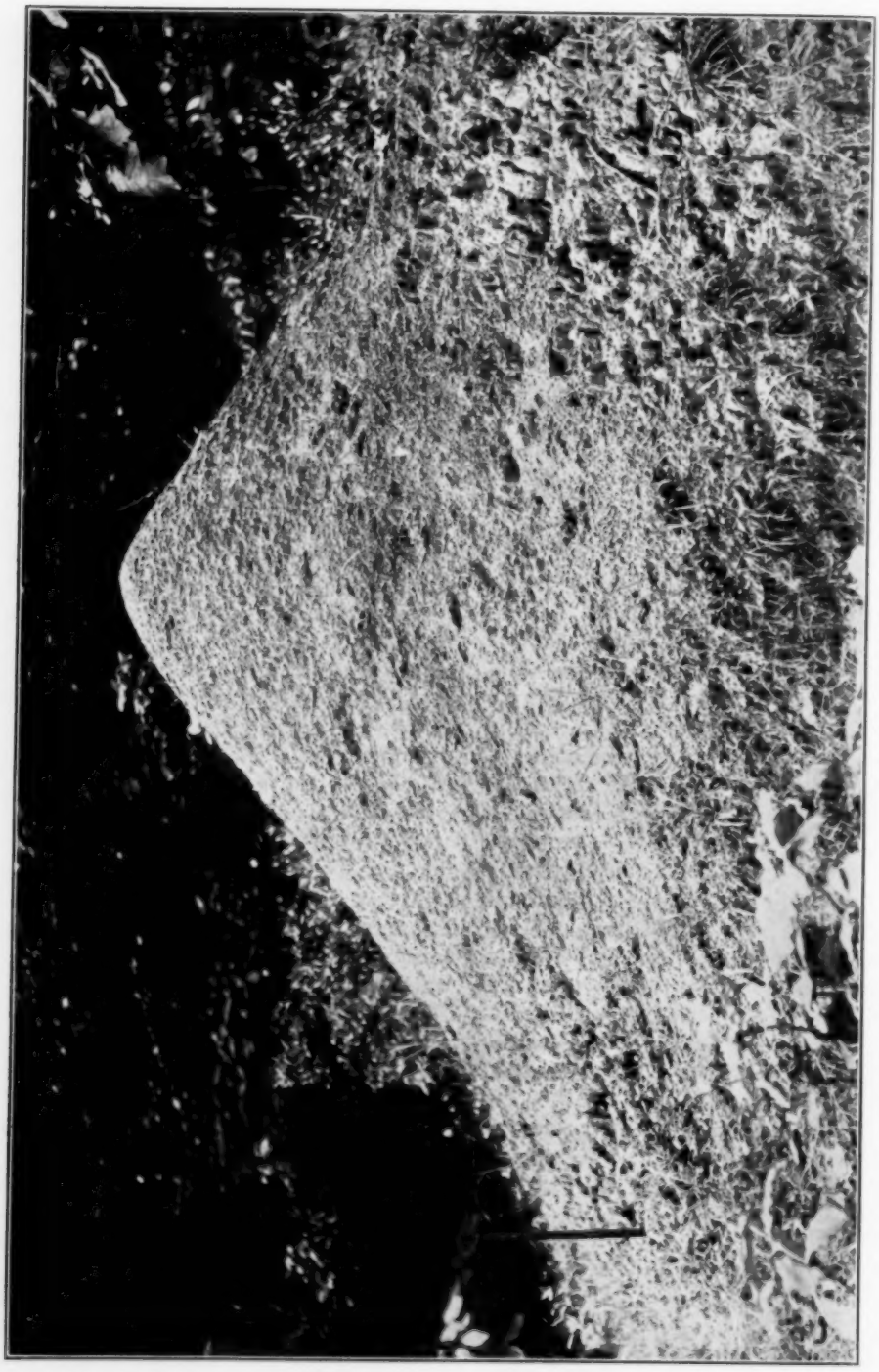

FIG. 1. ANT HILL

BUILT ON GROUND SLOPING TO N. W., HENCE THIS SIDE IS THE LONGER. FOOT RULE AT N. W. BASE SHOWS SIZE.

Some mounds show north slopes of 55 degrees to the horizon and some south slopes of only 19 degrees to the horizon here in Maryland. However, this extension of the cone in one direction is not always referable to compass or sunshine; sloping of the ground upon which the mound was built may bring about marked extension of the mound down hill. In this region of old mine excavations many ant hills arise upon their steep slopes and the ants ever persist in carrying up the particles of clay and gravel that tend to roll down hill with the wind-and-rain action and even with the kicking of the ants themselves. (Fig. 1.)

Despite this Sisyphus task the mound remains distorted down hill, and as in the accompanying photograph the long gentle slope may be northwest and not at all to the south, as it might be on the level where there is no special reason for the particles to roll more in one direction than in the other.

FIG. 1. ANT HILL.
BUILT ON GROUND SLOPING TO N. W., HENCE THIS SIDE IS THE LONGER. FOOT RULE AT N. W. BASE SHOWS SIZE.

Architecture of the Ant Hill

The mound is not merely loose particles placed by the ant. The boy with stones to throw or the gent with a cane soon finds that the mound has an outer crust and a soft crushable interior structure. We may lift off the crust or roofing in small pieces part of an inch thick that crumble in our hands; earth mingled with more or less vegetable material, grass and leaf portions. The earth is sand or clay dependent upon the locality, and the vegetable matter, likewise grass and leaf portions, differs much in different regions. Pressure on the intact roof makes it yield and break in with from 2 to 25 pounds to the square inch, most often about 10 pounds. When there is much vegetable component in the adobe of the roof, penetration is easy, but on the other hand denudation is resisted and the steepest cones are built with utilization of pine needles as reinforcement. On the other hand, a rare mound may be found in which the stiff clay alone makes so firm a structure that a man may stand supported on the roof upon one foot. The roof is often strong enough to support a fox or owl that sits there to view the neighborhood, but the feet of deer crush through and leave breaks that the ants hasten to repair.

Observations in the field backed up with laboratory study of ants kept in confinement show that the strength of the roof is brought about by the rain that wets the dry materials placed here by the ants and draws them close together so that in drying they make a more homogeneous and coherent mass. The ants supply the raw materials and place them with reference to the ideal conical mound while the rain binds the loose building stones together and makes it a good roofing, but by no means an ideal one, as it is not rainproof and in long wet seasons the interior of the mound is muddy, indeed; so that one can sympathize with the native of Cecil County who marvelled that Providence had endowed the ant with such a fine house and yet with so poor a roof. However, we will see later that the roof is to be constantly reconstructed as the mound increases with the prosperity of the community, and a watertight roof might defeat this mode of enlargement. Thus the roof of the ant hill is made by bits of material wrested from the soil or picked up and merely laid in the right place, while the roof over the nest of a hornet is made of bits that are masticated and stuck together with secretions of the hornet.

With proper weather and warmth we see the ants running over the roof with such speed that the camera fails to show them. Up the mound a foot in three to five seconds; down the mound a foot in two to four seconds at 25° C. Those that run up soon deposit their burdens

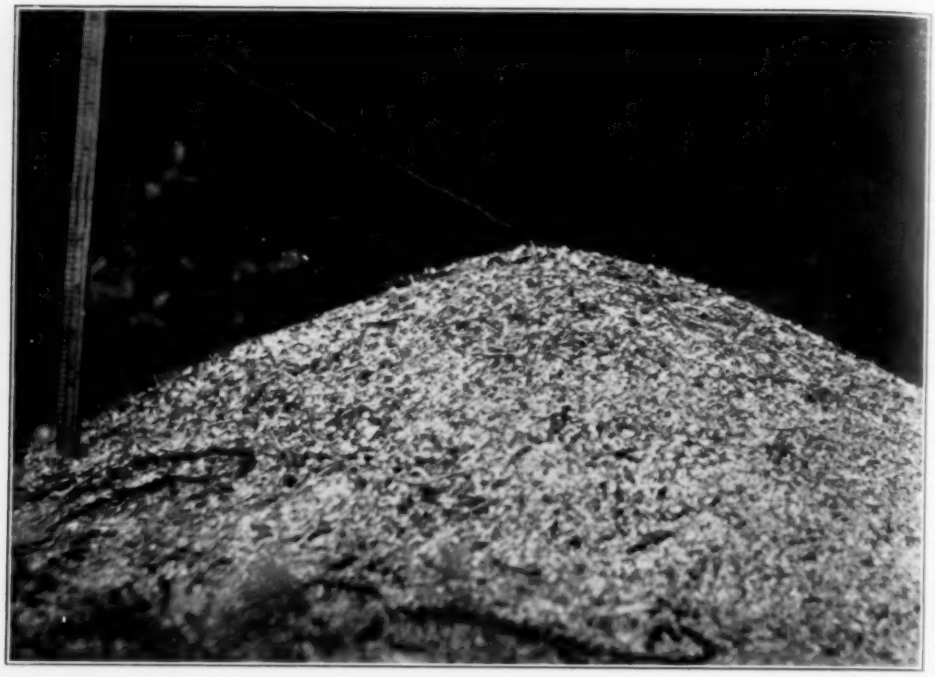

FIG. 2. CLOSE-UP OF SMALL ANT HILL

SHOWING ROUGH COVERING OF STICKS AND STONES PLACED THERE BY ANTS. FOOT RULE RISING FROM NEAR BASE.

and run down again for more, carrying pellets of earth, bits of stone or sticks larger than themselves, or sometimes rare finds such as shells of small snails or the droppings of caterpillars or of mice. (Fig. 2.) Many of these objects are collected from afar. Colored sawdust was brought sixty feet back to the mound, other particles are ever collected from the base of the mound when they roll down, and the ants more than make good the loss from the mound as they clean the base down even below the natural level, removing the top soil till the coarse stones of the subsoil are revealed in a depression all about the mound base, forming a Brobdignagian pavement court at the front doors of the building, all the ants' entrances being small holes here and there about the base of the hill, leaving the apex and sides commonly with neither door nor window.

Every ant is provided with a pair of mandibles each a millimeter long with blunt cutting toothed edge .4 mm long on the far part of each. Bringing these together as ice tongs the ant seizes hold of objects most firmly. If possible this object is held up in the air in front of the animal and thus we see sticks ten times the length of an ant advanced wavering up the mound, and stones and pellets of earth larger than the ants bodily lifted and rushed forward up the slope. Bigger things are seized and dragged behind as the ant turns about and goes nimbly backward tugging stones that may weigh up to 170 mg. though the ant weighs but 10 mg; as if a man were to drag an automobile without wheels up a grade of thirty degrees!

Why, having got such a firm grip, the ant ever lets go of the burden is quite an unsolved problem; the ant may run in straight or sinuous path up the face

of the mound even over the apex and round about or may stop at various places short of that and release the burden; sometimes the stone or pellet may be taken into some open door when there are such on the face of the mound. The load is dumped as if some wound-up internal mechanism were released after a time rather irrespective of the position upon the mound. Yet the sum total of all these dumpings makes the mound rise in conical form as if all the particles had been dropped as in an hour-glass from a central shute.

Moreover, there seems no collaboration amongst the ants. Each does as does another without any visible knowledge of what the other is doing, and never do two ants help move the same stone; if too utterly big for one to drag the stone is let lie, though it may be tested. The symmetry of the mound seems mirrored in each ant's mechanism, and if the symmetry is destroyed by local injury, by removal of large parts, even a half, the ants work the more upon that injured part till the wound is healed over. The apical region is the newer and softer part of the ant hill where loose objects have accumulated and have not as yet become stuck together. A penknife that stood up on the hardened lateral face sank an inch when stuck into the apical region.

Beneath the roof we find the internal structure of the ant home. The stick that penetrates the roof continues to penetrate with pressures of 30 to 50

FIG. 3. ANT HILL CUT OPEN

SHOWING SPONGY INTERIOR IN THE SOUTH PART; THE NORTH FACE HAS THE STEEPER GRADE. GRASS GROWS ON THIS MOUND, BUT THE CATBRIAR IN THE BACKGROUND HAS BEEN KEPT OFF THE MOUND FOR YEARS BY THE NIBBLING OF THE ANTS.

pounds per square inch down a foot or more to the ground level or even deeper. In fact, the interior is not solid earth but a spongework whose walls collapse with pressure, and some of the bulk of the mound is mere air held in the internal passageways that constitute the real dwelling of the ant. Cutting into the mound the walls may crumble in sandy soil so that the structure is not easily understood, but in clay the walls stand firm and we comprehend that here is a continuous labyrinth in three dimensions occupying most of the space beneath the domed roof.

Some passageways seem rather horizontal and others approach the vertical, but here the ant has no such guide of structures at right angles all vertical and horizontal as the honey bee has in its hive. Many passageways run rather parallel to the sloping roof and others radial in the dome. Even in sandy soil we get the same idea of the structure of the labyrinth by allowing the mound to freeze in the winter and sawing into it; by infiltrating the sand with paraffine; by filling the passageways with plaster of paris and then washing away the earth between the passageways so that they now stand out as solid branching strands as shown in the illustrations; or by filling the passageways with paraffine, washing away the earth, replacing it with plaster and then baking out the paraffine to make a positive of the original mound. An ant coming home to its mound and entering at one of the many doors about the base finds itself confronted with a labyrinth with no exact horizontals, verticals, compass directions.

A horizontal view of a casting of some of these nearly horizontal passageways near the apex of the mound shows the irregular character of the branching of the former passageways here filled with plaster. The dark spaces are the regions from which was washed away the earth that once formed the solid buttresses that held the mound together. A vertical view of a like casting exhibits a tendency toward horizontal passageways and many diagonal, obliquely rising flights from story to story (the white areas are the sawed-off parts that continued the horizontal tunnels).

The earth buttresses here shown as dark spaces are all sizes and forms, but the tunnels or passageways are more uniform. Measurement shows them 4 to 20 mm in diameter and that the horizontal width is almost always greater than the height of each tunnel; the differences may be 2 to 3 mm, though often not so much, the norm of width approaching 9 mm and of height 6 mm. In such tunnels the ant has plenty of room, since with a length of 7 or 8 mm its antennae and its legs may spread apart about 7 mm and its height is but 4 mm; and the ant can crawl through a much narrower space when its legs are not so outspread.

Running at speed the ant very soon comes to a choice of ways, since the blocks or lengths from branching to branching are very short, scarce an inch, only 9 to 45 mm, with sometimes a norm of less than 25 mm. The solid earth not excavated by the ants is thus in buttress forms surrounded by streets, and in the denser labyrinth, where blocks are the shortest, to run all around a block the ant need go but four times 6 to 16 mm. that is, much less than 10 times the ant's own length. When the mound is abandoned and the roof no longer kept in repair these centers of blocks or buttresses remain as pillars of earth standing over the roofless mound.

The ant at each corner has a choice, as it were, of surface, elevated, or branching subways to advance in. The number of ways open to the ant at corners may be 3, 4, 5 or even 6. The streets or stairways do not diverge at equal angles; thus one corner presented

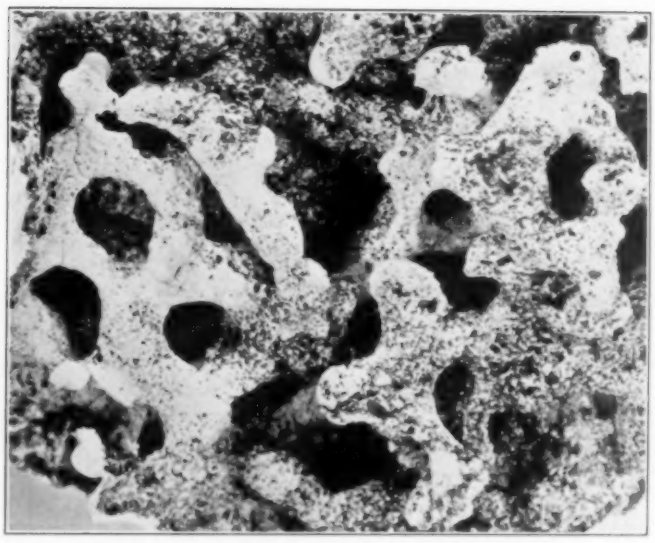

FIG. 4. TOP VIEW OF PORTION OF PLASTER CAST

OF INTERNAL STRUCTURE NEAR THE TOP OF A MOUND; SHOWING THE NETWORK OF PASSAGE-WAYS HERE FILLED WITH PLASTER OF PARIS; WHILE THE EARTHY PART OF THE NEST HAS BEEN WASHED AWAY, LEAVING THE DARK AREAS.

ways at angles of 11, 100, 130 degrees; another 95, 115, 155, another 50, 75, 120, 40, 72 degrees, all read clockwise. (Figs. 4, 5.) Compare all this with the most intricate of man's cities.

The parts of the mound most used by the ants and where most ants and young are to be found is far up above the basement entrances and must be reached by such unequally diverging and rising ways. Since the roof and upper levels seem to cut off all light the ants must find their way by mere chance, or else under guidance of other responses than those to light. It was Réaumur who saw that such labyrinths allow the ant to go up or down right or left or in any other way he may desire. But are there any signs along the way, and how do the ants read them in order to go to a region they prefer? These innumerable passageways show one limitation of the possible wanderings of the ants. Each has a definite floor. While ants can walk perfectly well upside down in these tunnels there is evidence that they habitually walk upon what is the bottom and not the ceiling, for each tunnel, except it be a rare vertical one, has the lower side plastered smooth with earth as if the feet of ants had trodden down the mud dropped in transporting the mined earth. The ceiling, on the other hand, is not smooth but rough with projecting bits of stone, etc., as if freshly dug out by the ants without any subsequent smoothing. Thus the ants seem to keep on the down side of all the streets they travel, rather than take the inverted elevated course.

During the summer this ant hill, with its roof and inside labyrinth that seems a maze that the ants must somehow learn to thread, serves as resting and breeding place and center of life of all the ants of one community. But as winter draws near more and more of the ants go down deeper into the earth by shafts they have dug leading rather straight downwards beneath the mound and diminishing in numbers with few side connections as depths increase from

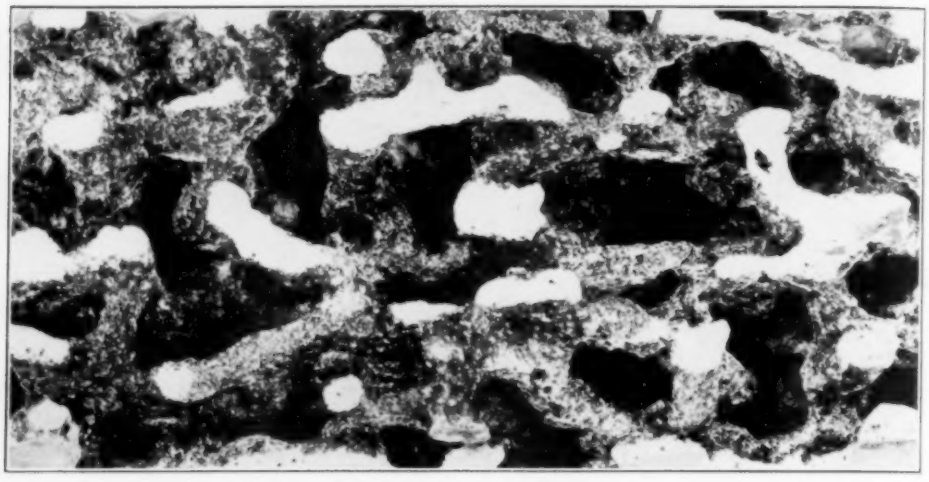

FIG. 5. PIECE OF PLASTER CAST

SHOWING SUCCESSIVE STORIES CONNECTED BY RISING WAYS ABOUT THE EARTHEN PILLARS, HERE SHOWN AS DARK, WHILE THE DEAD WHITE AREAS ARE THE SAWED-OFF CONTINUATIONS OF CASTS OF PASSAGEWAYS.

one to several feet. These tunnels in subsoil are lined with mud from the topsoil, and the linings may stand out clearly from differences in color, as in the burrows of earthworms, and these linings lead one to assume that these tunnels are frequently used, supposing that the lining is the result of accidental droppings trodden down by feet.

From the netted labyrinth down into these shafts all the ants finally descend and crowd together here and there in dense masses with compacted limbs. Here they rest during a third of the year in a torpid state, able to move their limbs and even to stagger about when exposed, but no longer capable of working.

As ants do not maintain a high temperature they soon are cooled below a working basis, and this dependence of activity upon temperature of the surroundings is most striking. It was found that some of these ants, kept for two hours at zero Centigrade, could at one degree not only move their legs but scrabble along weakly and walk very poorly at two degrees, could walk on the ceiling of a glass test tube at 2½ degrees, though slowly. Cooled down to 4 degrees below zero these ants remained inert but soon recovered when the temperature rose. In March or later or earlier, according to temperatures, the ants begin to come up from the depths and some emerge onto the outside of the mound.

There these ants begin the first work since last November, and it is the repair of the mound damaged by the winter or perhaps cracked from shrinkage. Later, food will be sought and later still breeding will begin. As far as known there is no storage of food down in the earth to carry the ants through the winter, but each ant may have stores within its own body; as all have shared with others during the summer, the ants may go into winter quarters with surplus and the entire community may pull through the long season of inactivity and little need of food. In this sense these ants "are a people not strong, yet they prepare their meat in the summer."

When a whole community was kept in

the laboratory it was found that after resting at low temperatures they could be aroused to work by connecting their dwelling jar by means of long glass pipes with other receptacles filled with earth, and then supplying dark heat to these pipes. The ants went to the warmer regions and basked in the heat, then dispersed and gradually came into the new region of earth to be excavated. Here they set to work as if to construct a mound. Moreover, for many days the ants that had been warmed went back and forth actually carrying sister ants from the cold jar through the long glass tunnel to the warmer abode. Let us then assume that it is the effect of temperature that is largely the cause of these annual treks from the mound to the subcellar and back again. The observations of Holmquist upon a closely similar sort of ant indicate that some individuals remaining in the upper levels respond sooner to the call to the surface and that these ants may induce other ants to go up.

It must be emphasized that in temperature responses, as in most other respects, each individual ant may differ much from other ants. If then temperature is a potent factor in getting the ants out of the labyrinth into the subcellar shafts and from these up into the labyrinth again (in the fall the subsoil is the warmer, in the spring the mound is the warmer) may it not be that temperature differences within the mound are important guides to the ant's finding its way? That such differences in warmth are to be found in different parts of the mound will be shown later.

Origin and Growth of an Ant Hill

The ant hill is a communal affair, and it is rare in this kind of ant that a new mound is started by just one ant; on the contrary a sort of swarming or colonizing process takes place, many ants starting a hegira to some new place. It may be that the entire community will then desert the old mound and thus it will stand deserted indefinitely and sink into decay. Thus when a mound and its inhabitants were taken many miles and transplanted into the woods of Johns Hopkins grounds the ants after some days of working on the old mound material all set off for a place they selected fifty feet away, on the edge of the wood in the sunshine, and there they built up a new mound with the new materials they found at hand. These ants carried with them their eggs and young and some of the quaint insects that have the habit of living only in ant mounds.

But the emigration may involve but a part of the whole community. For several days ants from a certain mound rather in the shade were studied as they ran forth forty feet to the north and established a new little mound in the open sunny place. Here again day by day old ants and young were bodily carried away from the old mound to the new (sometimes, to be sure, back again). Eventually the new colony cut loose from the parent community and has lived its own life for some years as a growing community, while the old parent community still continues in the same old place.

The architecture of a new ant hill starts with a very primitive expressing of ant activities, mere digging down into the earth, as common ants do. But several or many ants all dig at once, opening up several shafts near together. Biting their ways through the top soil and then the subsoil the ants bring out pellets of earth that are cast down near to the mouth of the shafts, accumulating as mere handfuls of roughly scattered earth pellets, rising up amidst the grass without order. The winter comes long before the mound is completed, but year by year the work is continued

toward a perfected dome. The few inches of earth accumulated between the shafts tends to stop the mouths and must be ever removed by the ants till finally the mound is allowed to close over at the top and new openings are made near the base, since within the heaping mass side connections between the shafts were soon established allowing the ants to run from shaft to shaft and thus making a continuous network within the earth mass thrown up. Eventually the mass of earth thus mined and brought to the surface and heaped as a rude mound is supplemented by extensive collections of materials found ready on the surface of the earth and brought little by little by the ants to add to what they had mined. In all these efforts to build a home the weather is a most important factor; neither too hot and dry nor too wet and cold will serve the building ant well.

Observations of ants digging into clay in glass boxes and in glass tubes show that no progress can be made in dry clay nor in mud, while sand can be scratched away by the front legs, dog fashion. But when the clay is plastic the two jaws of the ant moving sidewise stick into it and are then brought together to wrest off a little bit as a man's hands shoved sidewise together might squeeze off clay. This requires great efforts on the part of the ant, painful to observe. Not only are the jaw muscles worked, but the whole head is twisted on the shoulders to worry off a bit of the tenacious clay, and the legs are braced so that no part of the ant seems at rest, giving a picture of a terrier biting at a root in its frenzied digging. Maybe twenty such minute bits, each 5 to 160 hundredths of a mm, are pulled loose and let fall, coming away with a noise that may be heard and imitated, and then rapid sweeping movements of the head and front feet shove the accumulated bits back beneath the worker who may gather them up in a pellet and carry this a short distance from the end of the drift to leave it there and to return to the work again and again. Meantime other ants may come near and pick up the pellets and carry them away farther, sometimes poking them into side cracks and vacant spaces, somewhat as honey-bees fill up crannies with propolis. Thus some are working as pick men and others as carriers, or cleaners up, and very slowly but perceptibly the tunnel advances into the resistant clay. An inch of clay in a tube was carried away and scattered along a foot distance. Ants worked the material by relay with each ant carrying the clay a short distance and so on till finally taken out to the surface.

The weather sets the rhythm the ants dance to; when it is too dry to mine the ants collect surface materials that may roll down the slopes as the heap assumes a mound-like form, but the ants carry this up again till the mound is strewn with crumbling dry particles. Then rain not only cements the roofing together but arouses the old primitive mining urge in the ants, who running over the roof enter here and there by minute openings that they soon enlarge and thus communicate with the ants within the labyrinth. Now each hole becomes a mine mouth, ants run in and out depositing pellets brought from within out on the surface so that soon the mound is pimpled over with little hillocks or steeper turrets, one about each shaft. With the drying sunshine the work slackens and the little chimneys are closed in at the top and by additions of pellets to the outside and the collecting of foreign material to add to the new roof the chimneys become little dimples and finally are lost in the gradual thickening of the whole mound surface. It seems that the materials that are thus rapidly brought out of the ant hill after a rain are mined out from

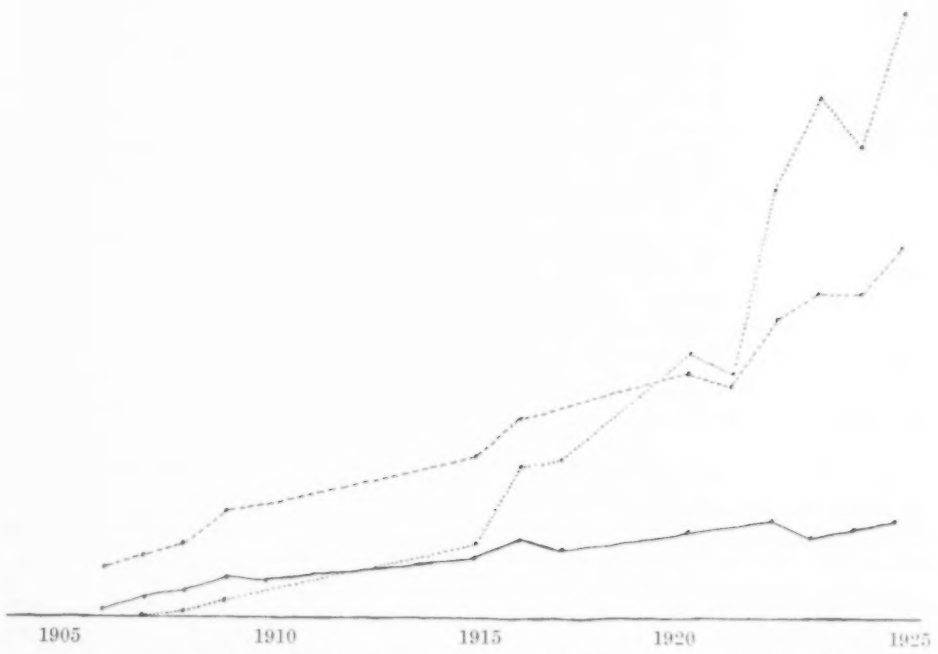

FIG. 6. CURVES TO SHOW GROWTH OF ONE ANT HILL FROM 1906–1924, INCLUSIVE.

THE LOWER CURVE SHOWS INCREASE IN HEIGHT UP TO TWENTY-SIX INCHES. THE BROKEN LINE SHOWS INCREASE IN DIAMETER UP TO 92 INCHES. THE DOTTED CURVE RISING HIGHEST REPRESENTS THE INCREASE IN CUBIC FEET UP TO 20 (MAGNIFIED BY FIVE AS COMPARED WITH THE OTHER TWO CURVES). ALL SHOW DEPARTURES FROM UNIFORM INCREMENT AND SOME SETBACKS.

the substances of the mound and, in part at least, from the substance of the old roof. Thus we get the picture of the mound advancing by waves of growth dependent upon the weather; long dry seasons making a thick roof from collections of surface materials and brief wet periods resulting in the tearing out of the old roof to make new attic labyrinths, the inside of the roof being put on the outside; it might be said that the roof is turned inside out without there being any laying bare of the inner life of the community.

By mining, collecting, remaking the roofs, the ants fabricate the mound and increase it year by year. An ant hill 3 inches high and 9 wide grew in a few months to be 5 high and 15 wide; the next year it was 6 high and 18 wide; the next year, 9 high and 26 wide: 6 years later 42 wide; and 12 years after that the mound was 88 inches wide with contents of some 30 cubic feet, as compared with 1/100 cubic feet, when first observed.

Curves representing this mound from 1906 to 1924, inclusive, show that growth was not uniform and might have setbacks in height and even in cubic contents, when the wear and tear of the elements was not entirely made good by the work of the ants (Fig. 6). Each ant hill, however, has its own individual vicissitudes and one may advance fast or slow and another fail.

FOOD BROUGHT TO THE ANT HILL

The ant hill may be large or small not only from age or youth but from the

degree of success of the organization that owns it, and this in turn depends greatly upon food supplies. These ant hills flourish near small trees, not that the ant eats the leaves or the bark, but that they depend largely upon the juices of the trees as their daily bread. However, the juices of the trees are handed over to the ants by certain sucking insects, such as plant lice (aphids), tree-hoppers and scale-insects, which seem unable to utilize all the sugars they get from the sap of the trees and must needs cast off some of it, which, being sticky, is a nuisance if kept near and were best far removed.

Near every mound we expect to find such feeding trees, oaks, pines, black locusts or tulip-poplars from which processions of ants run back and forth, some ants coming to the tree from the nest and others returning from the tree to the nest, running rapidly in ill-defined paths in scattered open formation. Here again the effect of temperature is patent; though, if it be warm, the ants work all night the chill of evening slows their pace and they may run along at a slow rate of twenty seconds to cover one foot at 11 degrees while at 30 degrees they run it in only 4 seconds.

Coming then to the food tree up they go rapidly at the rate of a foot in 8 to 16 seconds at 25 degrees and helter-skelter down again even faster, a foot in 4 to 10 seconds, although they are loaded with clear liquid that makes their bodies swollen and translucent and adds to the weight they had going up actually about one third.

If you can follow these ants running in lines up the tree trunk you will find them spreading out along the branches and finally paying visits to the little suckers that produce the sweet liquid known as honey-dew. This is taken by the ants and eagerly drunk to fulness and ultimately carried to the home mound to be shared with young and old who lack, as more is taken than the individual needs and she then serves as a carrier for the community.

To seek out this honey-dew the ants may run a hundred feet over the earth and then up and out on the trees and yet find their way home with so many changes of direction. Though some ants run from source to source taking in many drops here and there others stand about for many minutes before they too return, but all ants near the source of food are most keen to pick a fight with any intruder and possibly this strong defense saves the mild producers of honey-dew from some attacks; if so the ants pay for their honey-dew by protecting the producers as well as acting the part of garbage man, who can salvage much good food from what is given him.

Getting the honey-dew is easy, since it is so freely offered upon mere suggestion that even clumsy man may induce its discharge by mere tickling, yet the running up and down the tree in the hot sun is hard work. At the bottoms of such trees we find holes that lead into the earth and descending ants entering in as if they might be going by tunnels back under ground to the ant hill. However, when we mark the ants we find that they come out again and either up the tree again or off over the surface of the earth. Examination proves these go-downs to be but small imitations of nests in which the ant does but rest a while and clean herself and sisters, and obtain the dampness and freedom from sunshine that home affords.

Important as is this honey-dew for the maintenance of the community it is by no means the sole food of this ant, and much meat food is brought back into the home, with some benefit to the forest, as often injurious insects are thus destroyed.

Nothing is so powerful as to quell the

fierce pugnacity that dominates the life of this ant. The wind, the rain-drops, all animal living things from cows to minute insects, if moving about, may be rushed at with open jaws ready for attack; strange chemicals, soft or sticky substances, a burning taper, plants growing upon the mound or near it, in fact, almost anything new and unusual may call forth this dominating pugnacity. Going about as with a chip on each of its six shoulders the ant attacks little insects single-handed, and only when they give very potent repellent juices does the ant retire to wipe its jaws; else the insect is killed and carried back to the mound, however far away. In killing, both ends of the ant come into play, the dull jaws seize and cut slowly, while the other end of the body ejects strong formic acid that may enter the wounds.

No insect is too large to attack, but with big prey several or many ants may take part. Each ant showed the same tactics, seizing, irrigating with acid and dragging away. When the prey was small the ant lifted it bodily and bore it forward high in the air, but if larger the one ant turned about and dragged the heavier prey as it ran backwards all the way to the home mound, which was somewhere behind the ant.

The great big insect seized by many ants is ultimately dragged home and into some entrance; but the way is long and beset with obstacles and much time is spent. To begin with, each ant pulls back from the prey wherever it has happened to seize it; the ants radiate out from the prey, sometimes the struggling mass advances in one direction, sometimes in another. The initial seizure and straining in all directions seems like the "stretching process" described by Major Hingston, who saw certain red tree-ants of India apparently killing their prey by stretching it in all directions; the prey being as upon a rack.

On this way home the prey may be worried and bitten till it comes in pieces, to be carried off separately. While juices are taken from the prey (which may be an earthworm yielding much nutrient fluid), as it is killed and dragged along, the carcass finally disappears within the darkness of the ant hill. What becomes of that food mass may be surmised from a study of mounds partly of glass within the laboratory; here such prey is let lie in some part of the labyrinth for many days, occasionally licked and apparently drained of its juices for the benefit of the community.

How so many ants, pulling each its own way, "having no guide, overseer or ruler," ever manage to bring home the large unwieldy cicada or earthworm is by no means easy to understand. At times we are tempted to give the chief credit to those stronger ants who are able to pull both the prey and such ants as may be riding upon it, or tending to drag it in some other directions. It may be that the real domination in this social organization is a sort of oligarchy of ants stronger in muscle and in inner urge to do as ants should do, while many weaker ants are subordinate, as exercising minor powers.

The Ant Hill Used for Breeding

The ant hill is more than a home for the ants in which to rest and feed and be protected. It is the nest in which the eggs are laid, the young reared, and the resting pupa in its spun cocoon cared for till the "callow," or weak, pale adult emerges to soon begin its duties for the commonwealth.

The emptied cocoons are tough little bags which the ants have no further use for and we find them carried out and cast loose upon the roof of the mound where they soon accumulate in numbers that cause comment and enable us to gain some idea as to the success of the

colony that has thus brought as many new lives into it as there are emptied cocoons displayed. A very large ant hill having 212 cast-off garments to the square foot was estimated to have brought forth 13,144 new members of the family, enough to make good the losses from accidents and enemies of many kinds that tend to decimate the colony, though each ant may live several years, probably, if such fate does not overtake it.

All these new ants arose from eggs that were tended and cared for by the common working ants who feed the young as well as all the adults mutually; however, the eggs themselves were laid by a few specialists, the so-called queens, that have little part in the community save this all-important one of making the eggs for the workers to attend. While the workers have little part in egg production they have the needed powers to care for the eggs they did not produce. The queens may be few up to 33; one mound contained by actual count 8,228 workers and only 11 queens. As for the male ants they are found for but a short part of the season, and, however necessary for the continuance of the community, they perform nothing in the daily round of food getting and working at the ant hill.

The ant hill that serves for breeding year after year through some decades owes its continuance to very many factors, and the successful addition of young is not the least of these. Here again temperature underlies this activity. It is well known that ants in captivity do not breed unless the temperature is high enough and also the young grow but slowly or not at all if the warmth is not sufficient. As the ant seems to have little means of keeping its own body warm, in the cold, it can not furnish the needed warmth for the young but must trust to the finding of warm places and seasons, for breeding success. The mound furnishes just this needed heat for breeding, but the mound is only a transformer and conserver of heat, received from the sun, as appears from such curves as that shown by the results got by thrusting thermometers into all parts of an ant hill and reading them hour by hour through a September day and night. As the curves show, the air is warmed in the day and cooled in the night and this is true also of the earth. The ant hill also feels the diurnal pulse, but the sum of all the temperatures at apex and sides of the ant hill shown by the dotted zone (Fig. 7) is more uniform, not dropping off at night, as did the general soil outside the mound. In this case one aspect of the hill, the southwest face, is given a separate curve rising greatly in the day and falling low at night; this part acts as the furnace for the community, taking in much heat by day and losing much by night, but the whole mound tends to conserve some of the day's warmth and carry it over from daylight to daylight. Here again the weather determines the results. Long rain and cloudy weather makes not only a wet dwelling but a cold one, and work and reproduction are deferred or slowed up.

That the ant hill serves as incubator for the eggs and brooder for the young is connected with its architecture. Built of innumerable connecting rooms under a common roof that is greatly heated, more in one part than another, the walls heat the inner air and, as in the closed attic of a man's house, it is long before this heat is dissipated. Observing the ants in the open we find they collect their young and eggs in certain parts of the mound and according to both temperature and moisture conditions transport them hither and thither, generally through the internal labyrinth, but sometimes outside over the roof. In the laboratory also we see these ants carry their young from

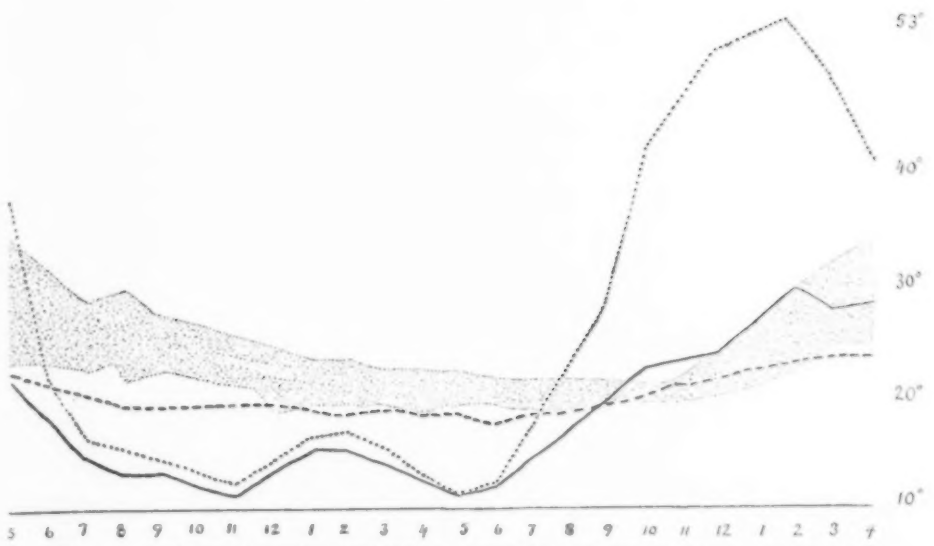

FIG. 7. TEMPERATURE CHANGES DURING TWENTY-FOUR HOURS IN SEPTEMBER.

THE DOTTED BAND INDICATES THE GENERAL INSIDE WARMTH OF AN ANT HILL VARYING FROM 20 TO 30 DEGREES BUT STAYING RATHER UNIFORM FROM 5 P. M. (ON THE LEFT OF THE DIAGRAM) TO 4 P. M. THE FOLLOWING DAY (ON THE RIGHT). THE BROKEN LINE REPRESENTING EARTH TEMPERATURES NEAR THE ANT HILL IS GENERALLY ON A LOWER LEVEL AND SHOWS THE EARTH NOT WARMED UP AS MUCH AS THE HILL. THE SOLID LINE CURVE FALLING LOW IN THE NIGHT TIME AND RISING TO A MAXIMUM ABOUT 2 P. M. SHOWS THE TEMPERATURES OF THE AIR. THE DOTTED LINE GIVES THE CHANGING WARMTH OF ONE PART OF THE HILL, THE S. W.; ALMOST AS COLD AS THE AIR IN THE NIGHT BUT RISING IN THE DAYTIME NEARLY TO 53 DEGREES, CENTIGRADE.

cooler to warmer areas, but there is a limit to the heat they select and they shun too warm a place as they cease also to work on the sunny exposures of the mound when the sunshine makes it too hot. The ant hill not being built at the equator of the world receives more heat on one face than on others and furnishes the choice of temperatures that the ants make use of. This heat may be held for some time after the sun is gone and so there is not as much interruption to breeding as would arise without this conservation, which depends upon the ant's engineering abilities.

That the heat rays and not the light of the sunshine serve the ant was shown by keeping an ant hill with its inhabitants in a dark room for more than a year. Here the ants proceeded to build, to mine, to collect stones and sticks, to get honey and meat food, to care for their young and to transport them, all with reference to greater areas of greater warmth produced by dark electric stoves. While this ant in nature lives in part in the darkness of the earth and in part in the sunshine of outdoors it can build, collect, find its way to and from the mound, feed and breed in the dark, under these laboratory conditions it had not before experienced.

RÉSUMÉ

The ant hill is a ton or so of materials collected by the ants through many years of labor and put together to serve as the home for the group of thousands of ants that build it.

Each ant works individually without any apparent connection with other ants, having, apparently, in its own

body the ideal of the ant hill that is to be and which once achieved must ever be repaired and maintained by its labor.

The hill that is built arises only under favorable conditions, and so many of these conditions are supplied by the sun that one may almost say that the ant and the sun have entered into partnership; the sun adding the capital in the form of heat and the ant supplying the plan and the executive ability for the enterprise.

The sun's contributions ebb and flow with the motions of the earth. In winter the business of the ant hill is at a standstill; the sun gives too little heat; the ants retire deep beneath the ant hill, where they rest in subcellars till in spring the sun again contributes to the hill such heat as will gradually draw the ants forth into activity.

Again every night insufficient warmth retards the work of the ant, though within the ant hill some of the warmth of the day is stored up and utilized by the ants. On the other hand, at midday there may be too much heat supplied by the sun and then the ants cease to work on the mound.

More indirectly the sun helps to shape the ant hill, for the clouds that the sun is responsible for modify the work of the ant and the rain that may fall upon the mound changes the character of the ant's work so that alternations of rain and dry are effective as alternations of day and night, winter and summer, in enabling the ant to cooperate with the sun towards the perfection of the ant hill.

No ant hills long continue except they have the optimum exposure to the sun; those in the shade are abandoned. Moreover, some ant hills show in their outward form the influence of the sun, being built by the ant more toward the sun than away from it.

In brief, the location of the ant's hill and its structure as well as the use it may be to the ants depends upon the warmth the sun furnishes.

The sun as well as the ant is responsible for these tiny mountains, these mere ant hills; and so much is the ant hill a product of temperature that we might fancy that sun-spots may leave some trace in these ant hills!

THE BROAD POINT OF VIEW IN PHYSICS

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WHEN Friedrich Nietzche some fifty years ago was proclaiming the new dogma of the superman, it is highly improbable that he had in mind the mathematical physicist. It is therefore a curious illustration of life's little ironies that at the end of the third decade of the twentieth century increasing popular interest should acclaim as the modern "Übermensch" the gentleman who can tell us what this universe is made of and how it really works, reciting the story in language so teeming with symbolism—with ψ's and ζ's and χ's—that to the humanist it must almost seem as if the ancient Greeks had come to life again to give heart to the classicists. It is not surprising that the modern versions of the "De Rerum Natura" should be so fascinating to the layman, yet there must also be a lurking bewilderment in the mind of the latter. Everything should be so clear, so manifest, and yet somehow even after reading Jeans and Eddington he finds it all rather elusive. Perhaps after all there is some excuse for pausing awhile and pondering over the old question—"What is physics?" It is a large question, and the answer to it will of course vary from age to age. But there are a few points of view which do not seem to suffer from over-emphasis. These we wish to examine here.

Definitions of physics have not been lacking. They run all the way from that of the late W. S. Franklin: "Physics is the science of the ways of taking hold of things and pushing them"—which must titillate the mental palate of the engineer, to that implied recently by Dr. Paul Heyl: "Physics is a state of mind," a definition to tickle the fancy of the philosopher. However, to define is ever difficult; perhaps one should be content to say that physics is the business of the physicist and then try to catch a glimpse of the latter at work. It is reported that when James Clerk Maxwell was a small boy he was fond of asking with reference to any new thing about the house: "What's the go o'that?" Nor was he content to be put off with a vague answer, but insisted on knowing the "particular go" of it. His later brilliant, though all too short, scientific career was a happy development of this childhood propensity. I think we may take this attitude as being significantly characteristic of the physicist—perhaps reaching its highest intensity in the mind of the physicist. What is his situation? He is confronted with a world of reproducible sense impressions of extreme variety. By a peculiar process of abstraction he separates certain portions of these from their surroundings for particularly detailed examination. He makes, for example, careful observations of motions of bodies and so develops the science of mechanics. He investigates what "meets the eye" and by a process which is still a mystery to many constructs the science of optics. And so the story goes. About all these things he weaves ingenious theories expressed in the symbolism of mathematics. And these very theories suggest new and more detailed phenomena for investigation. Thus the process of specialization has created that superb structure known as modern physics, so towering, so magnificent and yet unfortunately so little understood by those who gaze on it from the outside with so much admiration. There remains the task of gathering these specialized results into some kind

of whole—the process of integration, never an easy matter. It involves taking a broad point of view, a very broad point of view, perhaps more often associated with philosophy than with science, but one nevertheless very necessary for the latter. There is a world which physics has constructed. We leave aside the question as to whether it is the real world, for the question of reality has curiously enough little interest for the physicist. What is this world, what is it like and what must we do to understand it?

The details of the world of physics are multifarious and not so easy to grasp as a whole. But there is one thing which is really far more important than knowledge of the details and which moreover we can accomplish: that is, an appreciation of the method by which this world is constructed. Now if one in search of information on this head were to enter a modern physical laboratory, he would undoubtedly see some rather queer things—whole structures of complicated glassware enclosing equally complicated and intricate metallic parts, switches and elaborate electrical circuits. The talk may be all of electrons and photons, but the operations boil down to opening and closing switches and in most cases watching the position of a spot of light as it moves along a scale. And the results of all the operations will be found ultimately to reside in a set of numbers representing coincidences between this spot of light (or something like it) and marks ruled on a scale. The words "pointer readings" have already been made so famous by Sir Arthur Eddington that it would seem almost needless to re-explain them here. Yet the significance of the fact behind them is so overwhelming that it will hardly suffer from over-emphasis. We get so used to talking in terms of concepts like mass, force, energy, pressure, to say nothing of electrons, protons and the like, that it is difficult for the outsider to realize that the numbers we attach to the marks representing these things are derived from nothing but such coincidences. To be sure the way from the pointer reading to the symbol may be long and thorny. After a hard day at the laboratory collecting his pointer readings the physicist used to go home and spend an equally busy evening making marks on many pieces of paper trying somehow to connect reasonably simple combinations of marks with his coincidences of the laboratory. We have employed the words "used to" advisedly, for alas, by the time the average modern experimentalist has finished a good day's work in his laboratory, he is so tired out that he is usually willing to leave the scribbling process to another individual who is paid to spend his days (and nights) juggling with symbols and piecing them with pointer readings. This is the race of theoretical physicists, now becoming perhaps more prominent than ever before in the history of science. All this is merely to emphasize that the job of constructing the physical world appears to call for two types of workers: (1) those who follow up hunches by collecting pointer readings with the greatest possible attention to the intricacies of experimental technique (now a branch of scientific activity in itself) and (2) those who follow much the same kind of hunches by chasing symbols around on a piece of paper, hoping to see ultimately the evolution of some simple connections with the pointer readings.

For we must clearly understand that the physical world is not merely a collection of coincidences, but an elaborate description in terms of a number of physical theories. Hence it is necessary to understand what a physical theory means. Perhaps the most striking thing about it is that it is expressed in terms of symbols. The world of physics is a symbolic world, a fact which can hardly be sufficiently emphasized. And it is undoubtedly this symbolic character of

physics which gives the science much of its abstractness and so renders it difficult for many people to grasp. The extent of this abstractness is well illustrated in every field of physics and has always marked the power of its method. Even in what many would be tempted to call the simple and obvious case of the large scale motion of a material object, for example, the physicist has introduced the abstract concepts of velocity, acceleration, mass and force, etc., with appropriate symbols. Why should he do this? Is not the fall of a body a most simple sort of thing? Why should one try to make it more complicated? Why not leave it as it is—a simple interesting plain fact in the same category as that which children learn in their history books. The answer to these questions dates back to the time of Galileo, who sought to describe the motions of bodies so minutely that the assumption of a few simple relations should be competent to embrace all possible motions. These few relations are the principles of mechanics and if we tried to understand motion otherwise than in terms of them we should be forced to make a classified list of thousands, yes, even millions of individual motions each differing, in some slight respect perhaps, from the others. The question reduces after all pretty much to what we are willing to mean by understanding a thing. If we prefer to try to apprehend each separate motion as it presents itself to us in the simplest, crudest terms we know of, that is one thing. If on the other hand we prefer to put emphasis on a few things which appear to be characteristic of all motions so far observed and agree that every individual motion shall be understandable in terms of these few idealized relations and to the extent to which it manifests itself as a logical deduction of these relations, we are taking the attitude of the physicist, and indeed the scientist in general.

Without doubt the most amazing thing about physics is the fact that a careful description (involving abstract symbolism) of a very limited set of phenomena can suggest the assumption of a few simple relations among defined symbols from which by purely logical processes (*i.e.*, by the carrying out of operations well known to mathematicians) we can deduce the existence among these symbols of other relations which by an appropriate identification with operations performed in the laboratory can be shown to be confirmed experimentally. Herein we see indeed boiled down into small compass the method by which the physicist constructs the physical world. But such a highly concentrated statement contains elements elusive to a complete understanding and needs considerable amplification with commentary involving illustrations from actual physical theories. There are in particular several points deserving special emphasis. These will now be elaborated.

In the first place we should stress again the symbolic nature of the world of physics. It is difficult to overestimate the importance of a scheme whereby a mark on a piece of paper is made to represent a highly idealized concept which is put into correspondence with a certain group of laboratory operations of the type involving ultimately a set of pointer readings, through which numbers may be attached to the symbols. In this way we place at our disposal a set of quantities that can be handled in accordance with whatever mathematical rules we desire to follow. It must be clearly pointed out that more is involved than a mere shorthand rendition of a single laboratory operation. To illustrate, it is not merely as if, after going through a process involving the noting down of the difference in the levels of mercury in two tubes, the physicist decided to use the letter p to denote the result of every operation of this kind

and attach numerical values accordingly. There is a deeper significance to the process, *viz.*, the strong feeling that p should represent something which is derivable from a combination of other symbols representing in turn more primitive concepts. The symbol moreover should not be tied to a single type of laboratory experiment but should have a meaning for and be assigned a value through a great many at first sight apparently quite different kinds of operations. In this way it takes on a larger meaning and the use of symbolism becomes an instrument of great power. Of course the freedom which the use of symbols confers in the manifold mathematical operations to which they may be subjected enormously widens the scope of theoretical physics. It is just as if our powers of description were correspondingly widened and deepened. Consider how barren the ordinary verbal description of the phenomena witnessed in a vacuum tube may be compared with the richness and fulness of the understanding of the same phenomena through the symbolic method. There is indeed economy in this procedure, as has been many times stressed, but it is the kind of economy that for given effort brings to us many times the return that would be possible by the use of words alone. And of course the whole procedure of the assignment of numbers to pointer readings would be very cumbersome without the symbolic method. Yet we must be careful to point out that the use of symbolism does not limit the physicist to any particular variety of mathematical process. We usually think of the analysis involving differentials and integrals when we think of theoretical physics and for good reason as we shall see later. But Faraday did not use this method in his study of the electromagnetic field, and as Maxwell insisted, Faraday's use of lines of force is as symbolic as the differential equations into which he translated Faraday's ideas. One of the great merits of symbolism is the infinite variety of form which it may assume. On the whole the physicist has been rather conservative, allowing the pure mathematician to run far ahead of him in the trial of new schemes. Recently, however, there have been signs of a new attitude, a willingness to introduce symbols obeying operations which while apparently bizarre are full of power. For example while in much of classical physics most of the symbols used are those to which numbers may be attached and which therefore obey the ordinary number postulates, there is now no hesitation in dealing with symbols representing definite physical concepts which do not satisfy these postulates, *i.e.*, for example, such that symbol A multiplied into symbol B is not equal to symbol B multiplied into symbol A. At first sight the introduction of such symbols seems needlessly to complicate matters and to scare away the uninitiate. But the only question involved is one of familiarity: the student need only recall that A and B may be "operators" which in general do not obey the commutative rule. To illustrate, if A represents the operation of multiplication by x while B represents that of differentiation with respect to x, then $A \cdot B + B \cdot A$ becomes perfectly understandable.

The fact that the world of physics is a symbolic one leads to another very important conclusion not clearly understood by the layman if we may base our judgment on semi-popular articles by scientists in various fields. The symbolic relations which constitute the fabric of theoretical physics are of course all implied in the initially chosen fundamental relations—the principles of physics—and the symbolic operations agreed upon for the construction of the theories. Hence it seems only right to admit that a physical theory is but a kind of description of the phenomenal world in terms of these initial relations. When a person asks us about a certain event

he may say either: *Describe* to me exactly what you observed to take place, or, *explain* to me, if you can, exactly *why* that happened. Now both tasks are usually hard enough in everyday existence as well as in science, but I think most will admit that the second is much the more difficult of the two. It generally leaves us with a feeling of ultimate mystery to be resolved only by an appeal to some super-earthly power as a final "cause" for everything. The scientist and particularly the physicist may well be pardoned for viewing with suspicion the popular notion of explanation. His greatest successes have come through careful description in terms of a more or less abstract symbolism. This is after all the only "explanation" which he has to offer and it is certainly only fair to make this plain so that people who take science seriously may suffer no delusion as to its methods and accomplishments. The explanation of the physical universe consists in a description, the validity or desirability of which is to be judged by the success with which a large group of phenomena can be described in terms of a relatively small number of quite abstract concepts and relations symbolically expressed with the maximum economy in the use of symbols. To put it more crudely physics is interested in "how," not "why"—at least not in the sense in which children ask their flood of questions forever prefixed by that embarrassing adverb—hardly ever to be satisfied except by the last desperate reply, "Well, God made it so!" When the scientist discusses the "why" of things he really means in the last analysis the "how" and should leave the former to philosophers to handle if they wish. For science it is a superfluous word. To many scientists the above will probably appear to be a trivial discussion about verbiage, but a short conversation with the average layman will, it is believed, convince him that there is a real problem involved and to the confusion about it is undoubtedly due most of the average person's utter bewilderment about the nature of physical science or for that matter of science in general.

If we admit the essentially descriptive nature of physical theories the question arises: what is the test of the success of such a theory? This is a matter of great importance, but a somewhat difficult question to answer at all briefly. Obviously any phenomenon can be described in symbolic form if we are willing to use symbols enough and do not object to complication. It is no exaggeration to say also that the description is possible in a great variety of ways depending on the nature of the symbolic method chosen; some of these are seemingly more simple than others but all assume an air of familiarity after close study. Incidentally it seems that the view which regards the simplicity of a physical theory as largely a question of familiarity has hardly been sufficiently stressed. Why is it that we are so accustomed to say that a mechanical theory is simple, while a theory which discards mechanical concepts is "too complicated"? Is it not that our sense of familiarity with mechanical notions tends to give the mechanical theory an overwhelming advantage at the start? Recall how valiantly Lord Kelvin strove for the elastic solid theory of light against the electro-magnetic theory of Maxwell. He never could really "understand" the latter! The phraseology was outside the familiar mechanical mold.

The true test of the success of a physical theory is its ability to *predict*. Here is a matter that requires some elucidation. We have before us the task of describing or "explaining" in the physical sense some group of phenomena. As we have just pointed out, that is possible in a great many ways: we lay down some postulates and by mathematical deduction obtain a whole lot of relations

which can be more or less readily identified with the known experimental results. We then say we have a theory, or, better, one theory. Our confidence in it is certainly materially strengthened if among the many derived relations there are some which correspond to physical facts as yet undiscovered, but which are later found to be as predicted. We may not care to go all the way with Dirac in his recent pronouncement that the "whole object of theoretical physics is to calculate results that can be compared with experiment," a point of view which deliberately enthrones prediction as the sole function of theoretical physics, and effectually ignores the rôle that a concise simple description of large groups of phenomena plays in its structure. Indeed it is possible to criticize Dirac's standpoint from the following consideration. Suppose someone propounds to me this problem: "I intend to put together certain pieces of apparatus in a certain way and go through certain quite definite operations. Now I wish you to tell me exactly what I shall observe." Let us imagine that you are a good guesser: you tell the gentleman what he will find. He then proceeds to find it. Does this make you a successful theoretical physicist? The illustration is extreme but it points out a difficulty nevertheless. The physicist will not soon get away from the notion that there is a physical world which it is his function to construct independently of his ability to answer certain questions about individual phenomena. However in all soberness it is safe to conclude that the one sure test of the ultimate validity of any physical theory is its ability to predict new physical experience. These two elements: shorthand description and accurate prediction should go hand in hand as the fundamental criteria for the judgment of the theories which express the structure of the physical world; but the more important is the latter.

We have mentioned the abstractness of physics in the sense of the—at first—unfamiliar concepts which the physicist uses. It is well to emphasize at the same time the importance of the notion of abstraction in the construction of the physical world. The significance of this idea can be appreciated from the following illustration. Suppose physicist A wants physicist B to make a study of, let us say, fluid motion. Does he thereupon invite physicist B to betake himself down to the bridge over the river and watch the flow of the water for a long time, making careful note of every phenomenon he witnesses? Much interesting information of a general nature might be secured in this way, but as a matter of fact, it is not a procedure which a physicist would be inclined to recommend. He has learned to recognize the extremely great difficulty of framing a precise description of any group of phenomena taken as a whole. It is indeed the kind of difficulty that most people learn to appreciate sooner or later even without the stimulus provided by formal education! No, if the physicist wishes to study the motion of fluids, he adopts a quite different procedure: he studies the behavior of a very small portion of fluid under highly idealized conditions over a very short period of time. That is to say, from the totality of phenomena connected with the motion of fluids he abstracts a certain limited section for special study. It is precisely in this way that he constructs differential equations to describe symbolically the phenomena under investigation. For it is just such equations which provide a symbolic description of experience on a small scale, *i.e.*, what is happening in a very small region of space over a very limited interval of time. The expression of the fundamental principles of physics in the form of differential laws is not accidental nor is it forced upon the physicist by any *a priori* neces-

sity; it is merely an expression of his deliberate belief in the power of abstraction to lead to the most satisfactory structure for the physical world.

The implications of this method are too profound to receive anything like complete treatment in this place. Nevertheless there are a few points we must note. The method of abstraction leading to differential laws implies that the totality of any phenomenon has no effect on what happens at a particular place at a particular time, but that it is only events in the immediate vicinity which influence the event in question. In other words the "organism" point of view, so useful in studies of vital phenomena, is disregarded. Moreover, the use of differential equations leads to laws of physics which do not depend explicitly on particular places or particular times. This has been used by Maxwell as the criterion of causality in the physical world.[1]

It should also be noted that since the differential equations of physics are partial differential equations (*i.e.*, involve functions of several variables) they have a very agreeable wealth of solutions which need only the imposition of boundary conditions[2] to give them the precision which the physicist seeks in his final answer to any problem.

It will be remembered that the differential calculus was invented for the purpose of describing the physical world and on the whole we must admit that it has served its purpose very well. It is only in the quantum theory that difficulties appear in the process of abstraction and we meet with simple finite difference equations like the famous Bohr frequency condition $E_1 - E_2 = h\nu$ in place of differential equations. The law corresponding to such an equation has been called by Eddington "transcendental." Some have taken the view that since the realm of quantum theory deals with the atom, a discrete entity, we should no longer expect to be able to carry through our description in terms of differential laws—that there is no meaning to differentials when the symbol used is to be associated with something having a definite lower limit of magnitude. This standpoint has great plausibility but we must remember that it should not imply the impossibility of a description of atomic phenomena in terms of differential laws. It merely means that such a description may prove extremely complicated and may involve the introduction of new and unfamiliar concepts. If we turn back somewhat less than a century to the history of the endeavors to construct a picture for electromagnetic phenomena culminating in Maxwell's famous field equations (differential laws) we may perhaps gain a better perspective on our own modern problem and feel less sure of the ultimate overturn of the method of abstraction which has proved so powerful in the development of classical physics.[3]

A third important element in the construction of the physical world is the fact that the fundamental principles on which the structure is based are postulates, assumptions or hypotheses, in formal logical character very much like the postulates of mathematics. Since we often call them laws and indeed laws of nature, one may suspect that there is a wide-spread feeling that they express truths which the physicist arrives at

[1] We shall not attempt a discussion of causality, as such, in the present article. For its connection with the matter here considered reference may be made to: H. Poincaré, "Science and Hypothesis," Chap. IX; Clerk-Maxwell, "Matter and Motion," New York, 1920, p. 13; Moritz Schlick, *Die Naturwissenschaften*, 8, 461, 1920; 19, 145, 1931. See also H. Margenau, *The Monist*, January, 1931.

[2] See, for example, R. B. Lindsay, SCI. MONTHLY, 29, 465, 1929.

[3] Even in the case of statistical studies which deal with the behavior of large aggregates and which are becoming increasingly important in physics the differential method is still employed.

directly by experiment: hence they are by nature inevitable. This view is erroneous, as a careful investigation of any physical law will show. Let us, for instance, consider for a moment the first law of motion, an important part of the foundations of mechanics. The usual statement is that every particle in the universe remains at rest or continues to move in a straight line with constant velocity except in so far as it is compelled by a force to change that state. It is very interesting to observe how this law is treated in many elementary physics texts. A rather common form of expression is that the law is rather difficult to prove experimentally, but one observes that a hockey puck will travel a great distance on smooth ice before coming to rest and the smoother the contact between ice and puck the farther will the latter go on being once set in motion: *i.e.*, if the contact could ever be made perfectly smooth, the puck would continue to travel forever. The only trouble with this argument comes in the kind of curve which the puck would follow; presumably it is unconsciously supposed to be a straight line. As a matter of fact if the ice were perfectly smooth, it would be a parabola, as is perfectly evident from the behavior of a ball when thrown into the air, where there is no "resisting" surface. When faced with this problem the reasoner may naturally reply: "But then you are neglecting the force which the earth exerts on the object. It is this force which draws the particle out of the straight line." It is a matter of some embarrassment to have to ask how one knows about this force and thus to extract the admission that our only precise knowledge of the force comes from the observed behavior of falling bodies. By that time we are, I take it, almost ready to accept Eddington's version of the first law: "Every particle remains at rest or moves with uniform velocity in a straight line except in so far as it doesn't." Does this mean that the first law is a meaningless absurdity or at best a tautology? Hardly that. It means that we must view the first law as a postulate expressing the assumption that when the acceleration of a particle is zero the influence of all the other particles of the universe on that particle vanishes. By the very nature of things this assumption can never be tested directly. It does not need to be. Its true significance lies in the fact that if we accept it as a basis for mechanics, we can build a structure closely approximating our actual experience of the motion of bodies. This is test enough for the physicist. It is not appropriate here to enter upon a lengthy discussion of the foundations of mechanics. We have merely wished to point out that the laws of motion are not experimental laws but postulates. How then does it stand with the other formulations of mechanics—Hamilton's principle, least action, etc.? The answer is precisely the same. Always at bottom we have to do with hypotheses whose justification comes from their simplicity of form, their ability to embrace descriptively large groups of phenomena, and their ability to predict previously undiscovered phenomena. It may be thought superfluous to be reiterating this view-point which is now so completely the stock in trade of every physicist. The reason why it is not superfluous is that there has always been a subtle psychological temptation to treat every successful hypothesis as an established law endowed with all the sanctity which the notions of inevitability and necessity are supposed to confer. The temptation is strong but dangerous. The physical hypothesis of one century may be quite incapable of subsuming the physical experience of the next as is well illustrated by the history of physics. Some one has said

that the story of the development of physical thought is like a plain strewn with the bones of defunct physical theories many of which were based on hypotheses which seemed reasonable enough in their day. Think of the caloric theory of heat, the action-at-a-distance theories of electrodynamics, the elastic solid theory of light, all plausible but now fallen by the wayside. We must remember that from the logical point of view the hypotheses back of such theories are postulates of the same character as the seemingly most firmly established principles of physics like the conservation of energy and the second law of thermodynamics. The moral is plain: we must treat all such principles for what they are worth and no more and we must most particularly beware of philosophical arguments based on their supposed inevitability. A review of general scientific literature is sufficient to make clear that there is still some confusion over this matter. It is very possible, for example, that the tendency among some biologists to shun a physical basis for biology is founded on a misunderstanding of the most reasonable attitude toward physical laws.

Passing now to our fourth point of emphasis, it is absolutely essential for the successful construction of the physical world that the fundamental concepts shall be precisely defined. In particular every definition must have a meaning in that it tells us how to carry out some definite operation or set of operations by which we can ultimately assign a number to a symbol. Judged by this standard, what shall we say, for example, of a definition of mass, one of the fundamental quantities of physical science, as the "amount of matter in a body"? This is still to be found in some elementary texts designed supposedly to provide the student with a thorough grounding in physics. It is pernicious, for it has no meaning unless "matter" has been previously defined and a precise group of operations connected with the word "amount." It is hard to imagine anything more calculated to confuse the thoughtful student than this mélange of words. Suppose one were to be presented with a lump of metal and asked to assign a numerical measure to its mass. Is there anything in the definition cited which would show how to do this? Now there is at least one very clear and precise method of defining mass in mechanics. To be sure it demands a bit of simple analysis with a few hypotheses and hence needs more words than the above pseudo-definition; but it is useful because it tells us something. We need not go into details at this place but may merely remark that what we have said about mass applies equally well to the important concepts of force, energy, entropy, etc., all too apt to be loosely used, particularly in philosophical discussions of physical problems.

It is perhaps a bit unfair toward the philosophers but a physicist can never recall without a chuckle what Maxwell wrote about Herbert Spencer's appearance before Section A of the British Association for the Advancement of Science at the memorable meeting in Belfast in 1874. There is a note of deep significance in the exquisite foolery which makes its quotation very appropriate even to-day:

> Mr. Spencer in the course of his remarks regretted that so many members of the Section were in the habit of employing the word Force in a sense too limited and definite to be of any use in a complete theory of evolution. He had himself always been careful to preserve that largeness of meaning which was too often lost sight of in elementary works. This was best done by using the word sometimes in one sense and sometimes in another and in this way he trusted that he had made the word occupy a sufficiently large field of thought. The operations of differentiation and integration which appeared, from the language of previous speak-

ers, to be already in some degree familiar to members of the Section, were, he observed, essential steps in the normal progress of evolution. It gave him great pleasure to learn that members of Section A were now turning their attention to these processes. . . .

Modern literature, scientific, philosophical, sociological and economic, hardly knows a more overworked word than "force." One rarely picks up a newspaper without seeing a reference to some kind of "force" doing something or other. There is nothing intrinsically objectionable about this; it is presumably a matter for literary experts to work on. Nevertheless from the standpoint of the physicist it is absolutely essential that the term force shall be precisely defined and once having been defined shall keep its definition throughout all physical discussions and, what is more important, in all philosophical discussions based on physical assumptions. Only in this way will the laity be saved from the utter confusion attending the talk about "cosmic" forces in the same breath as the force on an electron in a vacuum tube.

What has just been said about force might be said with almost equal justification about the term energy. The utility of this concept like that of force and mass is in direct proportion to the preciseness of the meaning attached to the symbol which is given its name. The student who in his first acquaintance with physics is led to think of energy in a vague wishy-washy way as something which can be "stored" in a tank and drawn off through a tap is bound to meet with great bewilderment in his later study, particularly in questions connected with the physics of atomic structure.

The attitude of the present article could be illustrated further, but probably the preceding considerations will suffice to bring out the significance of what has been called the broad point of view in physics. Much that has been said is by no means new to physicists but undoubtedly warrants greater emphasis than some of them care to concede to it. If it accomplishes nothing else it should certainly suggest to the reader the need for the never-ending scrutiny of the fundamental concepts employed in the construction of the physical world. That this is becoming more and more a problem of vital interest may be seen in the numerous recent discussions of causality and uncertainty particularly with reference to quantum mechanics. It would seem that some of this discussion is marked by a dogmatism and air of assurance that ill accords with the fundamental purpose of physics. However the limits of this article do not allow a complete consideration of this important question (see footnote 1).

In examining the foundations of physics the physicist is coming to grips with problems which are of constantly increasing importance for science as a whole, since the method of physics—the method of symbolism—seems to be our surest means for the description of all nature. If this statement is dubious and there are apparently some who think it is decidedly so, we may be sure of this much at least: the only way to settle the matter is to appeal to discussions of fundamental questions such as have just been suggested. Certainly physicists are only too glad to join with their colleagues in all fields of science and with the philosophers in further intensive search for the answer to that elusive problem of the ages: how do we know anything anyway?

PRELIMINARY EXPERIMENTS ON EXTREME VOLTAGE FOR THE BREAKDOWN OF THE ATOM

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A NUMBER of most remarkable experiments to produce artificially the conditions of Rutherford's famous investigations concerning the breakdown of the atom by means of the α-rays of radium have been performed during the last few years in Germany by Drs. A. Brasch and F. Lange, of the University of Berlin.

If it would be possible to produce canal rays in sufficiently large electric fields, such as to come close to the energy of an α-particle emitted by radium, Rutherford's experiments could be repeated on a much larger scale. A simple calculation shows that canal rays of 1 milliamp intensity at sufficient voltage would produce the effect of several hundred pounds of radium. Several other advantages would arise besides the increased intensity of the effects: any such production of large fields should enable one to surpass the limited energies of the disintegrating radium atom, and furthermore the experiments would not necessarily be restricted to the use of helium, as is the case in the radioactive experiments.

The success of experiments of such kind is bound up in two conditions, the production of extremely high voltages and the construction of a discharge tube which withstands such potentials. For both problems the German scientists found a most ingenious solution.

The production of potentials of several million volts is well known to be exceedingly difficult and very costly, due to the fact that very soon the problem of satisfactory insulation of large, increased energies meets difficulties not yet surmounted. The losses in producing voltages of more than two million volts are almost prohibitive, and thus the task of producing 2 to 8 times larger potentials, necessary for the experiment in question, seems to be hopeless.

Here Drs. Brasch and Lange tried two new ways successfully. The first was to repeat the classical experiment of Benjamin Franklin, making use of the potential differences in the atmosphere during thunderstorms.

The region where thunderstorms are most frequent in Europe, situated in the Alpine region at the border between Switzerland and Italy, was selected. The Monte Generoso at the Lugano Lake was chosen for the experiments, since it is accessible and the configuration of its peak contracts the distances between equipotential planes of the atmosphere sufficiently to produce very large potential gradients. Here several different arrangements were tried of which the most successful one is sketched in Fig. 1.

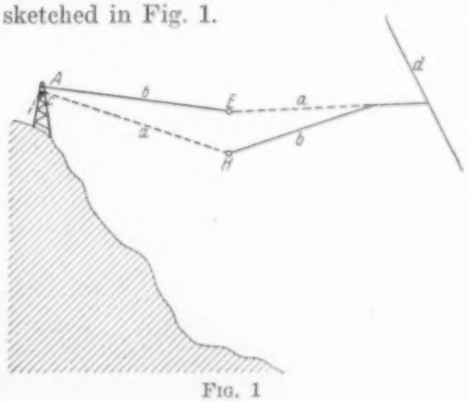

FIG. 1

At the upper end of a steep slope of the mountain the tower A was erected, which carried two connections with the cable d, the cable being suspended at two distant points not shown in the figure. The upper connection A–E–d consisted of the conducting part (b) and the non-conducting part (a), whereas for the lower part the insulating half (a) and the conducting one (b) were arranged in reverse order. The distance between A and the suspension point at d was between 500 and 600 feet. The altitude at which these were suspended was 4,500 feet above sea-level. Since A had the potential of the ground and d the potential of the atmosphere, the region between E and H worked like a spark gap of a condenser, and by varying the distance H–E (by lifting or lowering (a) by means of the pulley (c)) it was possible to measure the voltage which sparked across E–H. It was found that the arrangement worked not only by the immediate presence of a thunderstorm, but also due to induced charges by distant atmospheric disturbances. The distance of 54 feet was crossed easily by a discharge, which would represent a static potential of eight million volts. Considering, however, the short time over which a discharge lasted, the authors came to the conclusion that the potential must probably have amounted to between 14 and 16 million volts.

This proves that the atmosphere is able to produce potentials which are more than sufficient for the performance of the intended experiments as well as to prove that it is possible to collect these energies by rather simple methods, and many times less expensively than any artificial production by power plants.

The other problem—the construction of a discharge tube for such voltages—was solved in a similarly simple and unusual way. Here the principal idea is the following one: Experience in the construction of x-ray tubes for more than 300,000 volts has shown that the conduction of the charge at these voltages does not depend any more on the vacuum, but rather on the condition of the walls. Hence it is necessary to increase the size of such tubes to enormous dimensions, to create enough surface resistance so the tube may withstand such voltages. It goes without saying that the size of tubes for only several million volts would already be prohibitive. It was found, furthermore, that the gliding or conduction process along walls does not start immediately, especially if certain conditions are maintained. If it is therefore possible to have the potential act on the tube for a time so short that the wall charges are not yet set in motion a much smaller tube will work satisfactorily. Hence it is necessary to construct the wall of the tube in such a way as to make the motion of the charges very difficult. Such a construction was found by building a tube out of a large number of ring-shaped lamellae, as shown in Fig. 2.

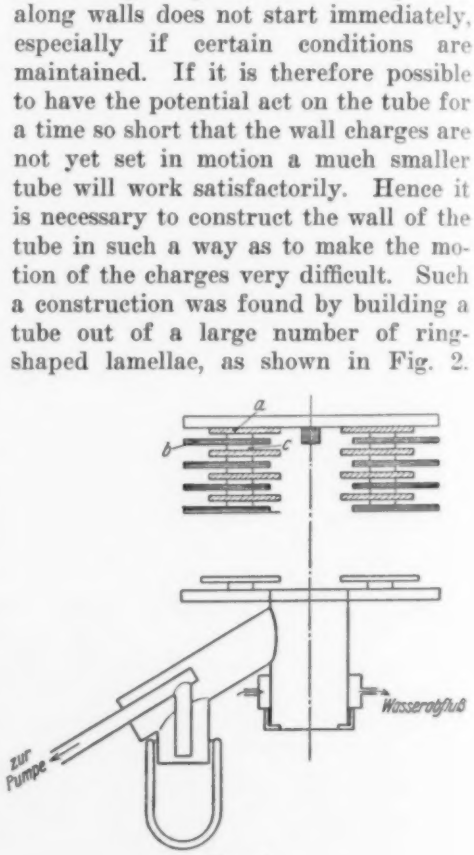

FIG. 2

Here the rings (a) consist of thin aluminum, (b) represent discs of a paper with very good insulating qualities, and

(e) are rubber gaskets. The whole structure was held together by pressure and formed a tube of less than three feet in length, of which the internal surface, however, had a length of 36 feet. The aluminum discs, producing an equal subdivision of the electric field, prevented the generation of fatal potential gradients along the walls. The tube was evacuated by a powerful mercury vapor pump and a liquid air trap shown schematically in Fig. 2.

By means of a surge-generator, which produced potentials up to 2.4 million volts lasting between one millionth to one ten-thousandth of a second, the authors were able to reproduce the conditions of atmospheric lightning on a small scale, fulfilling at the same time the condition under which such a discharge tube can work. The above tube was found to withstand two surges per second of 2.4 million volts and approximately 1,000 amperes, producing thus, in spite of the exceedingly short time of discharge, an x-ray intensity 10 to 100 times larger than the normal x-ray tubes running continuously at low potentials. The energy displayed in this tube during the time of discharge is many times larger than that of the total amount of radium which the earth contains, according to present estimates. The electrons necessary for the production of x-rays were introduced in the path of the discharge in a most ingenious way: Since the usual hot filament cathode could not be used on account of the presence of organic material, the gliding process of the charges along surfaces was utilized by introducing a sufficient amount of surface not subdivided, in the form of a bundle of porcelain capillaries. In a similar way, the ions for the production of canal rays were introduced into the tube by a stream of rarefied water vapor, which after having arrived at the anti-cathode was immediately condensed by liquid air.

The x-rays produced with the tube at potentials of 2.4 million volts proved to be equivalent to the α-rays of radium, penetrating lead 8 mm before losing half their intensity.

The canal rays of hydrogen produced at 900,000 volts penetrated aluminum to a depth of 8 microns.

After the success of this small tube, the construction of a generator producing 7 million volts and of a tube to use with it was started.

It seems thus that with these results experimental physics reaches a markedly new step in its development, since the work of Drs. Brasch and Lange shows that there are no longer any fundamental technical difficulties connected with the disintegration of atoms on a much larger scale than Rutherford worked in his pioneering experiments.

OUTSTANDING PROBLEMS OF THE OCEANOGRAPHY OF THE PACIFIC[1]

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INTRODUCTION

SINCE the physical and chemical properties of sea water and its circulation in the ocean basins determine the conditions of all the processes that take place in the sea, they are the features which demand first attention in considering the problems of the ocean. Therefore, this address will be devoted primarily to them.

Some elements in the marine environment are temperature and salinity of the water, the quantity of the gases and of the substances needed as plant food dissolved in the water, the relative alkalinity and acidity of the water (or OH^- and H^+ concentration), and the depth of penetration of light. Instability is characteristic of the ocean—there is movement apparently throughout the entire mass of the ocean water. The direction of the movement may be horizontal, upward, downward, or at any angle between the horizontal and vertical, including spirals. The maintenance of approximately uniform conditions within any oceanic realm is due not so much to the prevalence of a state of equilibrium as to continuous change, that is, the circulation of the water. Therefore, in evaluating the problems of oceanography, first rank must be accorded those that are concerned with oceanic circulation.

It is obvious that in a brief lecture, such as this one necessarily is, it is not possible to review the gradual development of such knowledge as we possess of oceanic circulation. Summaries of modern methods of hydrodynamical investigations of the sea have been recently published by V. W. Ekman, A. Defant, E. H. Smith and G. F. McEwen. During the past six or seven years there has been great stimulation of research on the problems of oceanic circulation. Much of the credit for this stimulation belongs to Alfred Merz, who contemplated an expedition to the Pacific and organized the *Meteor* expedition to the South Atlantic. Merz died in Rio Janeiro in August, 1925, but his plans for work have been carried out by the other members of the staff of the *Institut für Meereskunde* of the University of Berlin. Georg Wüst has published two longitudinal sections of the Atlantic Ocean and two for the Pacific, one for the Western and the other for the Central Pacific, and Lotte Möller has published sections of the Indian Ocean. Besides the compilations mentioned and the attempts of Wüst and Möller to interpret the results, there has been much other oceanographic activity, especially in the Pacific.

The work of the Japanese, the International Fisheries Commission in Alaskan waters and the Scripps Institution will be mentioned and later will be given its appropriate setting. Johannes Schmidt on the voyage of the *Dana* around the world has made important contributions. The greatest rôle during recent years in adding to knowledge of circulation in the Pacific was played by the *Carnegie*, which to the regret of all the world was destroyed in Apia Harbor in November, 1929, when its commanding officer, Captain J. P. Ault, lost his life. The results of other important

[1] First paper in a symposium, "Major Problems of Modern Oceanographic Research," at the meeting of the American Association for the Advancement of Science, at Pasadena, California, June 17, 1931.

expeditions are not yet available for use. They are those of the Russians in Okhotsk Sea and the northern part of the Sea of Japan, the Netherlands Expedition in the East Indies, and Sir Douglas Mawson's Expedition in the Antarctic Indian Ocean.

For this lecture an attempt has been made to utilize all recent publications, but necessarily they can not all be mentioned specifically.

Oceanic Circulation

It is desirable to begin this summary of oceanic circulation by noting a few principles that are generally known but need to be borne in mind during the following discussion.

The circulation of the waters in the oceans is due to causes which are fundamentally similar to those that produce circulation in the atmosphere. The main driving force is derived from energy radiated from the sun, but this energy does not impinge in equal amounts on equal areas over the surface of the earth. Because of difference in angles of incidence of the sun's rays, there is greater heating in the tropical and subtropical regions than there is in latitudes nearer the poles. Because of the inclination of the axis of the earth to the plane of the ecliptic, outside the tropics there is seasonal variation in the amount of heat received in each hemisphere, and, consequently, there is summer, when more heat is received, and winter, when less heat is received.

An important factor in directing the circulation of the waters of the ocean is the rotation of the earth on its axis. This, as is generally known, causes bodies set in motion to deviate to the right of the direction of motion in the northern hemisphere, and to the left of it in the southern hemisphere. Another factor that affects the movements of the waters in the ocean basins is that of the bounding continents and variation in relief of the ocean floor.

The movements of the atmosphere above the ocean surface exert important influences on the circulation of the waters of the ocean. Radiant solar energy and the deflecting effect of the rotation of the earth on its axis are largely the causes of atmospheric circulation, in a manner similar to their production of circulation in the waters in the ocean, but, since the density of air is much less than that of water, it is more mobile and, therefore, it may flow over the surface of the water and thus drag surface water along with it. The atmosphere also exerts two other important influences on water surfaces: one is because of evaporation; the other because of precipitation. If evaporation exceeds precipitation the salinity and, therefore, the density of the sea water is increased, but if precipitation exceeds evaporation the sea water is diluted and its density is decreased. Differences in salinity and temperature cause differences in the density of sea water. Unequal distribution of density causes unequal pressures and these produce movements of water masses.

Dynamical oceanographers have developed methods, which will not be summarized here, for computing the relative motions of water masses from their densities and the effect of the rotation of the earth on its axis.

Before beginning a survey of the circulation in the different ocean basins some features needed for understanding this circulation will be examined more closely.

Effect of Solar Radiation and the Rotation of the Earth on the Circulation of the Atmosphere and the Surface Circulation of the Ocean

If the earth were stationary and the sun revolved around it, there would be heating of the atmosphere and the waters of the ocean in tropical and subtropical regions and expansion of both

air and water. Both air and water, where heated, would move upward and flow toward the poles, in the region of which both would be cooled, and there they would sink and return to the tropical and subtropical regions as lower cool currents. The scheme, however, is by no means so simple, for the earth rotates on its axis and this causes a deflection of the movements of both air and water in accordance with the principles which have already been stated.

The combined effects of the differences in the amounts of solar energy that impinge upon the surface of the earth, the rotation of the earth upon its axis and the existence of the continental areas are to produce in the atmosphere over the oceans five more or less permanent areas of high barometric pressure. Two of these are over the Atlantic Ocean and are respectively known as the North and South Atlantic "permanent highs." Two are over the Pacific Ocean, where they are known by names corresponding to those for similar areas over the Atlantic, and one is over the Indian Ocean. These highs are approximately in latitudes 30° to 35° on each side of the equator in the Atlantic and Pacific Oceans, and south of the equator in the Indian Ocean. Between the northern highs and the equatorial region in the Northern hemisphere we have the northeast trade-winds. Between the southern highs and the equatorial region in the Atlantic and Pacific Ocean we have the southeast trade-winds. The Indian Ocean differs from the Atlantic and the Pacific in that it is subject to monsoon winds which are partly controlled by the relative pressure in northern Asia. The monsoon winds, however, mostly affect the surface circulation in the Indian Ocean and appear to have relatively little influence on the deep-water circulation.

On the north side of the two high areas in the North Pacific and the North Atlantic and on the south side of the high areas in the South Pacific, South Atlantic and Indian Ocean are the regions of the west wind drifts. The west wind drifts of both the northern and southern hemispheres are marked on their polar sides by lines or areas known as the "polar fronts."

The surface oceanic circulation rather closely conforms to the general scheme of atmospheric circulation that has been outlined. We have in both the North Atlantic and the North Pacific in tropical regions a movement of the surface waters toward the western sides of the ocean basins. In the Atlantic the water moves along the eastern side of the islands off the North American continent and off the continent itself toward the northwest, north and northeast, and recurves in the region of the west wind drift across the Atlantic. On the eastern side of the Atlantic there is deflection toward the south and southeast, and ultimately a vortex is completed, within which is the Sargasso Sea. There is a similar vortex in the South Atlantic. In the North Pacific we have the Japan current which, as is generally known, flows northward and northeastward off the east Asiatic coast, eastward across the Pacific south of the Aleutian Islands, and then is deflected toward the south and southwest.

Westward flowing equatorial currents are well developed in the Atlantic Ocean, where they lie mostly north of but near the equator. There is no strongly developed equatorial counter current in the Atlantic. However, the Guinea stream, which is very near the equator, flows from west to east. In the Pacific the equatorial currents are strongly developed and there is a pronounced equatorial counter current which lies slightly to the north of the equator.

As a result of the direction of the winds, which act upon the circulation of the waters, we have on the west sides of continents, along a more or less meridi-

onal line, upwelling of cold waters. Before this lecture is finished it will be shown that the scheme of oceanic circulation which has been outlined is of fundamental importance in controlling the distribution of marine organisms.

The Indian Ocean will, as regards the surface circulation, be treated only casually. As has already been stated the surface circulation is influenced by the monsoon winds. The equatorial counter current during the period of the northeast monsoons lies between latitude 10° south and the equator. During the southwest monsoons it is obscured. The south equatorial stream in the Indian Ocean is distinct throughout the year, but it is more pronounced during the period of the southwest monsoons. There is a north equatorial stream, really a westward monsoon drift, during the northeast monsoon (northern winter and southern summer); but during the southwest monsoon the direction of the surface drift is reversed and there is no north equatorial stream.

Configuration of the Ocean Basins

Although no attempt will be made to describe the different ocean basins in detail, a few of their more salient features need to be mentioned.

The Atlantic Basin. The S-shaped Middle Atlantic Rise extends almost the entire length of the Atlantic Ocean and divides it into two troughs. That part of the ridge north of the equator is known as the North Atlantic Rise, and that south of the equator is known as the South Atlantic Rise. Free communication between the northern end of the Atlantic Ocean and the Arctic Ocean is obstructed by the Iceland Swell, which extends from the northern end of Scotland to Iceland and is continuous to Greenland, and by the relatively shallow water on the west side of Greenland. Conditions on the two sides of the Iceland Swell are very different as the section across the part of it between the Shetland and Faroe Islands, known as the Wyville Thompson Ridge, as given by Murray and Hjort, plainly shows. On the north side of the ridge the bottom water, at a depth of about 800 meters, has a temperature of 0° C., whereas on the south side the water at a depth of 1,600 meters has a temperature of 4° C. Shallow bottom holds back from the North Atlantic the cold water of the Arctic Ocean. Two important submarine ridges that affect the circulation in the southern part of the East Atlantic are Walfish Ridge, which extends from the west coast of Africa in latitude 20° S. southwestward to join the South Atlantic Rise in latitude about 35° S., and the Atlantic-Indian Transverse Rise, which is an abruptly bent eastward continuation of the southern end of the South Atlantic Rise. In the southern part of the West Atlantic trough there are two submarine elevations of significance as regards the movement of the ocean waters. One of these is the Rio Grande Swell, which extends from the east coast of South America, latitude about 30° S., to join the South Atlantic Rise. The other is the Antarctic Archipelago, an arcuate series of ridges which extends from the southern end of South America towards the east and then bends westward to join Antarctica on the west side of Weddell Sea. Between Walfish Ridge and the Atlantic-Indian Transverse Rise there is the Cape Basin, which connects with the Indian Ocean. Between the Rio Grande Swell and the South Shetland Islands is the Argentine Basin which connects with the South Polar Basin, which in its turn lies south of the Atlantic-Indian Transverse Rise and communicates with the Indian Ocean. From what has been said it will be obvious that the Atlantic Ocean at its south end has two deep water communications with the Indian Ocean.

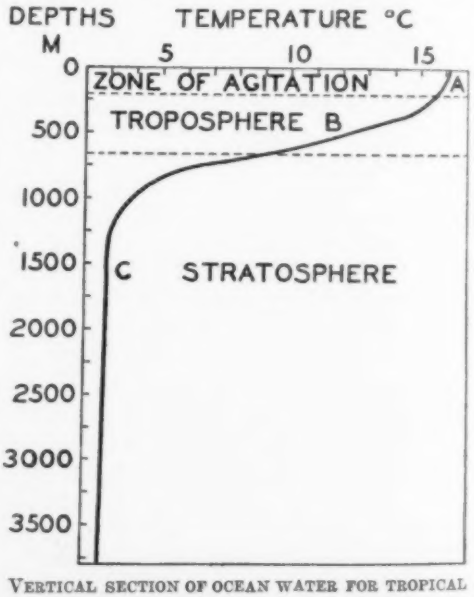
The Pacific Basin. The configuration

of the floor of the Pacific Basin differs in several important respects from that of all the other ocean basins. There are in it no continuous, more or less meridional, elevations such as the Middle Atlantic Rise, and there are no great transverse ridges such as Walfish Ridge and the Rio Grande Swell. At its northern end the Pacific is more or less cut off from the Arctic Ocean by the shallow water in Bering Strait and the Aleutian Islands, but some water appears to enter the North Pacific from the southwest section of Bering Sea. On the west side of the Pacific there is a succession of island arcs behind which are partially enclosed seas. One of these seas, the Okhotsk Sea, appears to be a source whence a part of the cold water in the North Pacific is derived. The southern end of the Pacific is widely flaring and is in communication with the waters on the north side of Antarctica and with the waters of the Indian Ocean south of New Zealand and Australia. On the east side of its southern end communication with the South Atlantic is obstructed by the island arc of the Antarctic Archipelago, which has already been mentioned. Although there are within the Pacific Basin numerous ridges, such as the Hawaiian Ridge, there are none that extend entirely across the ocean basin and divide it into north and south sections, such as is the case in the Atlantic basin. The bottom conformation of the Pacific is such as to allow a more extensive meridional movement of bottom waters and also a more unobstructed movement between East and West than in the Atlantic.

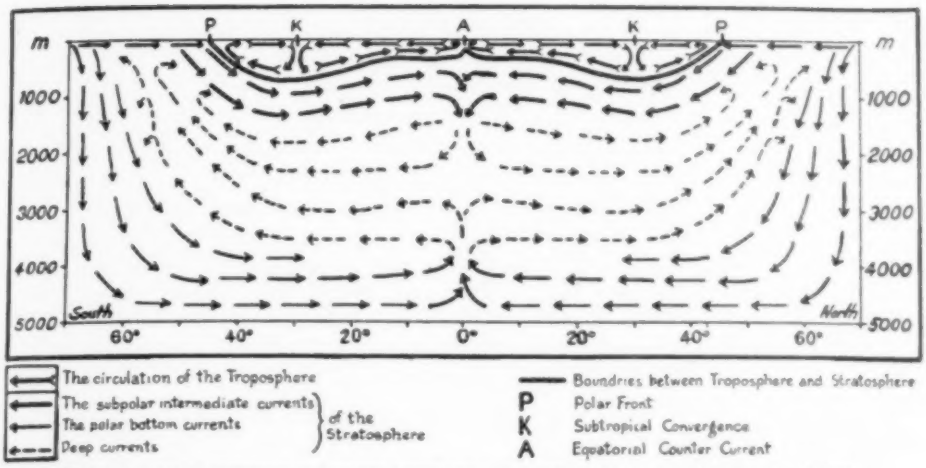
The Indian Ocean Basin. The Indian Ocean differs from both the Atlantic and Pacific Oceans in that its northern margin extends a relatively short distance north of the equator, and in that it is entirely cut off from any immediate source of water from the Arctic region. On the south the Indian Ocean is in fairly open communication with Antarctic waters, except that there is a rather large area of less than 2,000 fathoms deep above which rise Kerguelen, Prince Edward and other islands. Toward the East the Indian Ocean is in free communication with the southwest corner of the Pacific, and toward the West it is in free communication with the Southeast Atlantic, by means of the Cape Basin and the South Polar Basin.

The Deep Sea Circulation

A schematic section of conditions in the ocean within the tropical, subtropical and temperate regions will first be presented. According to A. Defant, the waters of the ocean in those regions may be divided into a troposphere and a stratosphere. The troposphere includes a surface zone of agitation of somewhat less than 100 meters in thickness, in which there is only slight reduction in temperature from the surface downward. Between the bottom of this layer and a depth of about 1,300 meters there is rapid decrease in temperature (the "Sprungschicht" of the Germans and



VERTICAL SECTION OF OCEAN WATER FOR TROPICAL AND SUBTROPICAL LATITUDES. AFTER DEFANT.



DIAGRAMMATIC SCHEME OF CIRCULATION IN A SYMMETRICALLY CONSTITUTED OCEAN. AFTER WÜST.

the "Thermocline" of writers in English) until the temperature ranges from 2° to 4°. Below the Troposphere is the stratosphere in which the temperature decreases very gradually and shows relatively little variation. In both high and low latitudes stratospheric water comes to the surface.

Wüst has suggested the following general scheme of circulation in an entirely symmetrical ocean: In the region of the equatorial counter current there is upwelling, and warm water moves on the surface away from the equator toward the north and south. In latitudes about 30° north and south there is sinking. On each side of each area of sinking there is a circulatory system, in one of which the water moves southward or northward, as the case may be, toward the equator, and in the other the water moves northward or southward, as the case may be, toward the polar front. Corresponding to the two polar fronts there is sinking of colder water of lower salinity which then moves from both the north and the south toward the equator as an intermediate current. In the region of the poles, polar water, because of its lower temperature and somewhat higher salinity, sinks and moves as bottom water from the poles toward the equator. According to Wüst, in order that the circulation may be compensated, there must be above the bottom water and below the intermediate current, a deep current that moves from the equator toward the poles.

This general scheme of circulation proposed by Wüst has been attacked by Castens. The criticism of Castens may be well founded, but nevertheless Wüst offers a working hypothesis which can be tested by the application of the dynamical methods developed by Bjerknes and other investigators of the fundamental principles of dynamical oceanography. Using Wüst's scheme of oceanic circulation a brief comparison may now be made between the circulations in the different ocean basins.

The Atlantic Basin. It has already been stated that the Iceland Swell and the shallow bottom west of Greenland almost completely isolate the main body of the Atlantic water from Arctic water on the north. There is no such obstruction between the South Atlantic water and the Antarctic region. Therefore, there is a sinking of surface water from the Antarctic in the region of about 50° south latitude. This water pushes itself

northward as a current of intermediate depth and relatively low salinity, 34.00°/oo to 34.70°/oo, nearly as far as 20° north latitude. Near the Antarctic Continent cold bottom water of a salinity between 34.65°/oo and 34.70°/oo sinks in the west basin and pushes itself northward in the West Atlantic Trough nearly to the equator, but in the East Atlantic Trough the northward extent of this water is cut off by Walfish Ridge.

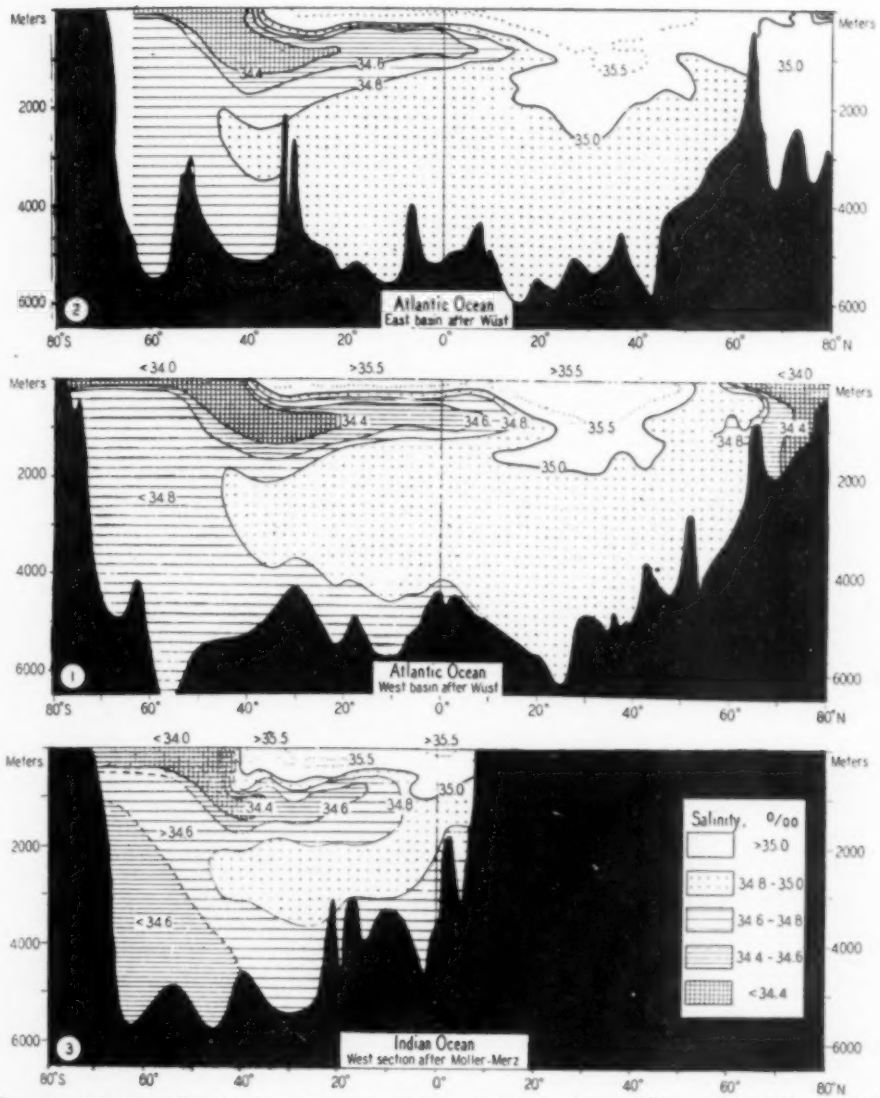
The deeper and bottom water in the North Atlantic is derived from several sources. One of these is the sinking of dense, warm water in the region of the northern subtropics. There is also sinking of water along the north polar front. Some Arctic water finds its way into the North Atlantic as cold bottom water, especially in the region of Davis Strait. One of the peculiarities of the North Atlantic Ocean is that there is a surface flow of less dense water into the Mediterranean through the Strait of Gibraltar, while there is along the bottom an outward flow, velocity over five knots per hour, of warm, dense water. The bottom water and the overlying deep water of the North Atlantic are therefore of composite origin. The combination of the various influences above mentioned causes the deep water in the North Atlantic to be of higher salinity and higher temperature than would otherwise be the case. This water pushes itself southward where, in general, it lies above the Antarctic water where the two come into contact, and below the intermediate water derived from the region of the south polar front. Its southward extent in the East Atlantic Trough is interrupted by Walfish Ridge. In the West Atlantic, where the northward extent of the Antarctic bottom water is not obstructed, a bottom temperature of 2° at a depth of 5,500 meters reaches to about 18° north latitude, whereas in the East Atlantic Trough, because of Walfish Ridge, water of a temperature of 2° does not reach farther north than the south side of Walfish Ridge, about 33° south latitude at a depth of about 3,600 meters. For the reasons above stated the deep and bottom water in the North Atlantic Ocean is derived from the north very largely by the downward sinking and subsurface intrusion of dense, relatively warm water.

The Indian Ocean. According to Lotte Möller there are in the Indian Ocean, between latitudes 5° and 40° S., four different kinds of water which, described from the surface downward, are as follows: (1) There is a subtropical surface layer with a salinity above 35.00°/oo and a temperature above 11° C. This water comes from the subtropical zones of maximum salinity on both sides of the Equator. It is underlain by (2) water of Antarctic origin which has a salinity of between 34.00°/oo and 34.70°/oo and a temperature between 8° C. and 2.5° C. (3) Under number 2 there is deep water which comes from the North Indian Subtropics and has a salinity of more than 34.75°/oo and is of higher temperature. (4) The bottom water which comes from the Antarctic and has a salinity between 34.50°/oo and 34.69°/oo with a temperature between zero and 1.5° C.

The semi-annual changes in the winds and the distribution of air pressure, because of their influence on surface gradients, produce changes in the direction of the deep currents, especially in the northwest Indian Ocean, but in the open ocean such changes are small.

Before leaving the account of the Indian Ocean, the effects of warm water of high salinity discharged from the Red Sea and the Gulf of Arabia should be mentioned. This water exerts an appreciable influence on the character of the water in the Indian Ocean.

The question of the exchange of water between the Indian and other oceans will now be considered. Lotte Möller has made suggestions regarding this



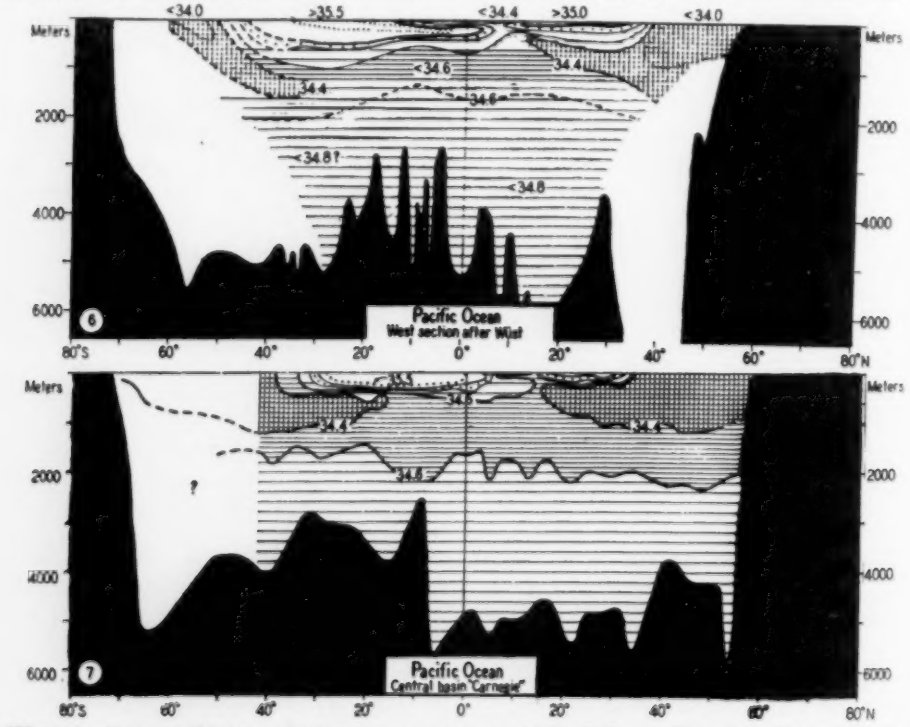
(Upper)—Atlantic Ocean, east trough, salinity section. After Wüst. (Middle)—Atlantic Ocean, west trough, salinity section. After Wüst. (Lower)—Indian Ocean, west part, salinity section. After Möller and Merz.

matter and they have been repeated by Wüst. According to Möller, in its upper 500 meters the Indian Ocean is filled with water of especially low density. The surface level therefore stands higher and accordingly there are gradient currents which are directed around the southern end of Africa into the Atlantic and south of Australia into the Pacific. Below 400 meters the pressure gradients along 40° S. latitude are directed from the Atlantic eastward toward the Indian Ocean and westward towards the Pacific, so that the West Atlantic represents a region of divergence, the West Pacific a region of convergence, of deep currents.

Along 55° S. latitude the pressure gradient is likewise directed from the Atlantic to the Indian Ocean. Accordingly, it can be postulated that within the Antarctic region, in so far as it belongs to the Indian Ocean, the Antarctic intermediate current flows toward the northeast, the deep current derived from the northwest toward the southeast, and, therefore, the water masses of the deep layers to a depth of 3,000 meters exhibit an interoceanic circulation. Below 3,000 meters the water masses in all of the oceans possess little difference in density, so that the distribution of the bottom water is dependent upon the configuration of the bottom.

The Pacific Basin. A brief summary of the principal conclusions of Wüst regarding the water circulation in the Pacific Basin is as follows:

In the west the boundaries of the troposphere are strongly marked and are pushed poleward as far as 55° S. latiture and 40° N. latitude, but in the east the troposphere is less developed and there it is meridionally very restricted. Since it has its greatest extent, both meridionally and vertically, in the west, especially in the southwest, the Pacific troposphere in its relations to the equator is quite asymmetrical. Corresponding to this structure, the warm water circulation of both hemispheres is asymmetrical. In a meridional direction it consists of a superficial spreading out of equatorial warm water masses of low salinity towards the poles as far as the subtropics and of an oppositely directed forward pressing of cooler, more highly saline water in the subtropical lower current. In the North Pacific this circulation is confined to a layer of water about 300 meters thick between latitudes 10° N. and 20° to 25° N. In contrast to this restriction, it shows extensive de-



(Upper)—Pacific Ocean, salinity, west section. After Wüst. (Lower)—Pacific Ocean, salinity, central part, *Carnegie* data. After Sverdrup.

velopment in the western part of the South Pacific, where the highly saline subtropical lower current can be followed in depths of about 200 meters through 35 degrees of latitude. The place of reversal of this asymmetrical warm water circulation lies in the West Pacific in 7° N. latitude, in the Central Pacific about 15° N. latitude.

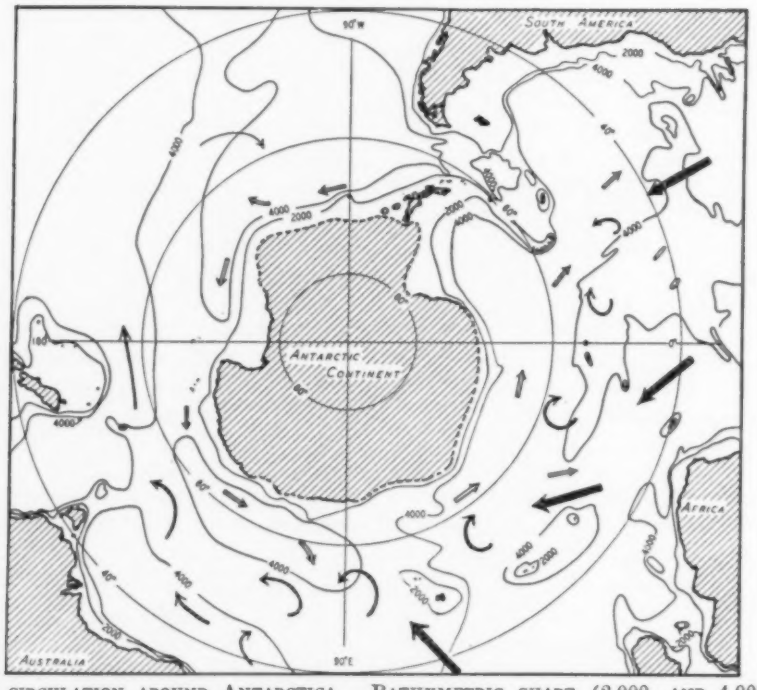
Regarding the cold water circulation the conclusions are that the water masses of the equatorial zone in the boundary regions of both intermediate streams, especially in the central part of the ocean, possess a tendency to sink and that here the source of the highly saline deep water should be sought. In the Atlantic the place of reversal for the stratospheric circulation is between 30° and 40° N. latitude, and with reference to it the circulation is quite asymmetrical. In the Pacific, in strong contrast, the stratospheric circulation possesses a nearly symmetrical structure. Two intermediate streams of nearly the same thickness conduct subpolar water from both sides to the equatorial zone, where it appears that the horizontal motion is transformed into a downward vertical motion. The place of reversal of this cold water circulation lies in the Pacific between 3° and 5° N. latitude.

On the other members of the stratospheric circulation, deep currents and bottom currents, there is only scant information. On the basis of compensation it seems necessary to assume that to the intermediate currents directed toward the equator there correspond highly saline deep currents directed toward each pole, that is, toward the south in the southern hemisphere and toward the north in the northern hemisphere. Indications of this are found in the disturbed temperature distribution in the section along the central part of the Pacific in depths between 1,500 and 2,500 meters.

Wüst suggests other possibilities for the formation of these highly saline water masses. He calls attention to the high salinity of the lower layers north of the Fiji Basin, where at a depth of 2,000 meters at Planet station 55 the salinity is 34.79°/oo. This excess of salinity might be expected to cause between 1,000 and 2,000 meters an excess of density to which compensating currents should correspond. The confining basins east of Australia may contribute to the formation of highly saline waters, but what their effect may be can be judged only after the acquisition of new observational data. Wüst also calls attention to the suggestion of Lotte Möller with regard to the Indian Ocean, which she shows contains in these latitudes, at depths between 2,000 and 3,000 meters, water of a salinity higher than 34.70°/oo, in the west even as high as 34.80°/oo, and that we must therefore reckon with a zonally directed deep current which carries highly saline water from the Indian to the Pacific Ocean.

Before considering the results of the recent work of the *Carnegie* and of those who have been connected with the preparation of the scientific reports on them, two aspects of Wüst's interpretation of the sources of the stratospheric water in the Pacific should be emphasized. One of these is the significance that he attached to the reversal of the two intermediate streams which conduct subpolar water to the equatorial zone and to his inferences that the horizontal motion between latitude 3° and 5° N. is transformed into downward vertical motion. The other is that he has considered the suggestion of Lotte Möller regarding the Indian Ocean as a possible source of the deep water in the Pacific Ocean.

H. U. Sverdrup has recently published an article entitled "The origin of the deep water of the Pacific Ocean as indicated by the oceanographic work of the *Carnegie*." This article deals altogether with the stratospheric water. A new section for the Central Pacific is based on



OCEANIC CIRCULATION AROUND ANTARCTICA. BATHYMETRIC CHART (2,000- AND 4,000-METER ISOBATHS) OF ANTARCTIC OCEAN, BASED ON MAP OF AMERICAN GEOGRAPHIC SOCIETY. LEGEND FOR FLOWS: OPEN ARROWS, ANTARCTIC WATER; HEAVY SOLID ARROWS, WARM WATER FROM THE ATLANTIC AND INDIAN OCEANS; THIN SOLID ARROWS, MIXED WATER. AFTER SVERDRUP.

the data obtained by the *Carnegie*. The great uniformity of the deep water of the Pacific, salinity between 34.50°/oo and 34.60°/oo, and a temperature between about 1° and 3° C., is most impressive. Sverdurp shows that this uniform water can not originate by the sinking of surface water between latitudes 3° and 5° N., nor can it be formed in the southern part of the Antarctic and thence flow as a bottom current toward the north and return toward the south at depths of about 3,000 meters, because the temperatures are too high. Sverdrup says that "it seems more probable to assume that the deep water which fills the Pacific is formed north of the Antarctic continent in the Atlantic, and especially in the Indian Antarctic Ocean by the mixing of deep water coming from the north and true Antarctic water coming from the south, and that this water enters the Pacific south of Australia and New Zealand." This is the virtual adoption of the suggestion by Lotte Möller, which was repeated by Wüst, but who inclined to the interpretation that has been invalidated by the work of the *Carnegie*.

Sverdrup discusses the effect of the Antarctic Archipelago on the movement of Antarctic water into the South Pacific. The water movements around the periphery of the Antarctic Continent would tend to be from the east toward the west, but the deflecting effect of the earth's rotation must be taken into account. Sverdrup correctly remarks that

> the extension of the Antarctic Archipelago towards the north prevents this water from continuing into the Pacific when flowing west, and the bulk of the water must, therefore, enter the Atlantic Ocean. The restricted communication between the Pacific and the Atlantic seems thus to account for the fact that the

returning deep current carrying warm water of high salinity toward the south is most conspicuous in this (the Atlantic Ocean). This returning current must also be deflected toward the left, which in this case means to the east, and the returning current from the Atlantic must therefore enter the Indian Ocean, as pointed out by L. Möller. In the Indian and Atlantic Oceans we thus find a flow of cold water of low salinity towards the northwest and a flow of warm water of high salinity toward the southeast. Considerable mixing of these different types of water must take place and increase of the salinity of the cold water from east to west and the decrease of the salinity of the warm water in the opposite direction may be regarded as the results of such mixing. The mixing processes appear to be most pronounced in the eastern part of the Indian Antarctic Ocean where at depths below 2,000 meters a great basin is filled with water of temperature between 1° and 3°, and salinity between 34.6°/oo and 34.8 per mille. This water is nearly of the same type as the deep water of the Pacific. The uniform character of the water seems to be more pronounced south of Australia where the temperature-observations indicate conditions which are very similar to those in the Pacific but the salinity-values are unfortunately lacking from this section.

All the available data point strongly in the direction that water of the same type as the deep water of the Pacific is formed in the eastern part of the Indian Antarctic Ocean, and that the origin of the deep water of the Pacific has to be sought there. This deep-water probably enters the Pacific through the opening south of New Zealand, but the inflow must be very slow and the deep water circulation of the Pacific correspondingly slow.

Mention should here be made of a very recent publication by M. Uda in which he shows that off the east coast of northern Honshu and Hokkaido cold water of the Oyashiwo sinks beneath the warm water of the Kuroshiwo. These observations bear upon the problems of the source of a part of the intermediate water in the Northwest Pacific and of the larger quantities of dissolved oxygen in the Northwest than in the Northeast Pacific.

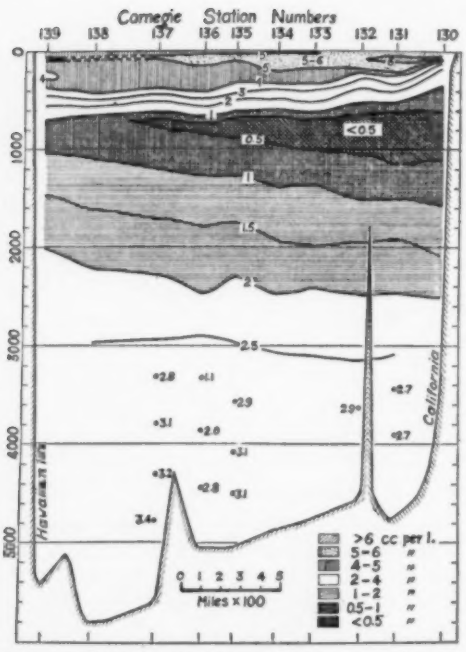
After having briefly outlined the general scheme of circulation for the different ocean basins in accordance with the most recent interpretations, the effect of this circulation on the habitats of marine organisms will be briefly considered.

Oxygen In The Sea

Although the study of the vertical and horizontal distribution of oxygen in the different oceans has received attention for a number of years it is only recently that it has become possible to consider the subject in a comprehensive way. The work of the *Meteor* in the Atlantic, that in connection with the *Carnegie* and the Scripps Institution in California, that of K. Ito in Japan, and that of J. Schmidt on the *Dana*, are particularly significant. Recently Moberg has summarized the information for the Pacific and compared conditions with those in the Atlantic. Subsequent to Moberg's publication, K. Ito has published an account of the results that he obtained in the southwest part of the North Pacific, and the results of the *Dana* have appeared in print. According to Moberg, four layers of water can be recognized in the Eastern Pacific: (1) One near the surface in which the oxygen content is high, (2) an immediately lower zone in which photosynthesis is active and there is the maximum quantity of oxygen, (3) a zone in which the oxgyen content decreases to a minimum, (4) a deep layer in which the amount of oxygen slowly increases with depth but is always less than that in the surface layer.

The amount of oxygen in the surface waters along the coast of southern California is a function of the temperature, as Moberg has shown. The water is virtually saturated, but the quantity varies with the temperature according to the well-known laws of the solubility of gases in liquids.

The general oxygen relations between San Francisco and Honolulu have been summarized by Moberg. The minimum value in the minimum layer is 0.2 ml. per liter. At one station, *Carnegie* station 151, approximately latitude 12° N., longitude 138° W., the amount of oxygen



SECTION, SAN FRANCISCO TO HONOLULU. SHOWING DISTRIBUTION OF OXYGEN, ML. PER LITER. AFTER MOBERG, *Carnegie* DATA.

was virtually nil and this condition prevailed from a depth of 100 to 400 meters.

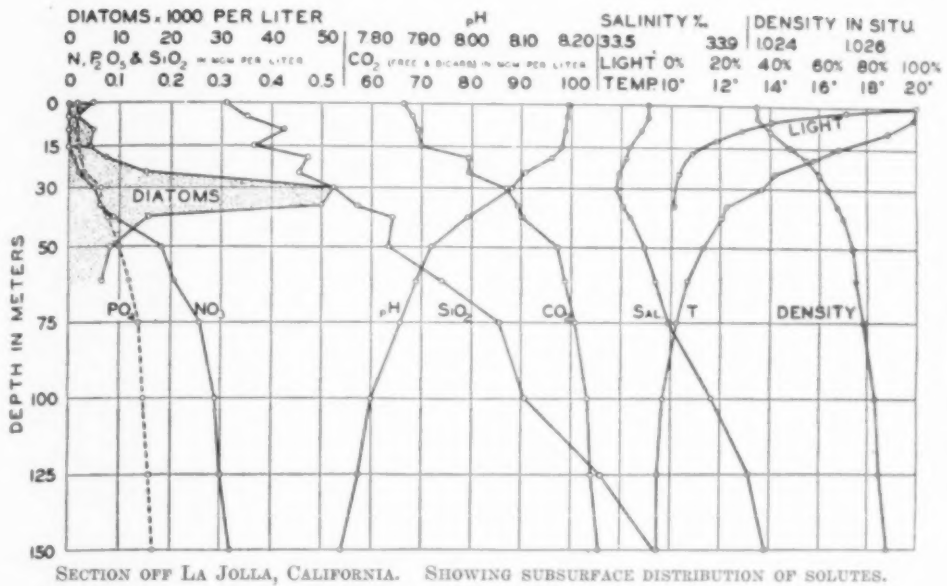
Moberg has compared conditions in the Pacific with those in the Atlantic. There is in the Atlantic a minimum layer somewhat similar to the minimum layer in the Pacific, but the amount of oxygen is greater in the Atlantic than in the Pacific. Below the minimum layer the amount of oxygen in the Atlantic is decidedly greater than in the Pacific. This difference between the oxygen distribution in the Atlantic and the Pacific is significant for a number of reasons, one of which is the bearing that it has on the source of the deep water and the bottom water in the Pacific, and another is because of the influence that it may exert on the vertical distribution of organisms.

According to K. Ito, there is in the Western Pacific no such oxygen deficiency as is found in the Central and Eastern Pacific. Explanations for this condition are at hand, but they will not be given here. The results of the *Dana* are in accord with the conditions already indicated.

Because of the oxygen deficiency over so great an extent of the Pacific, Moberg concludes that the deep water of the Pacific has lacked contact with the atmosphere during a longer period than has the deep water of the Atlantic, and he is of the opinion that most of the deep water of the Pacific enters that ocean by way of the southern Indian Ocean. Furthermore, he expresses the opinion that because the water in the South Pacific below 2,000 meters contains an appreciably greater quantity of oxygen than that at corresponding latitudes of the North Pacific a northward flow is indicated. In the North Pacific, however, since the oxygen content below 2,000 meters is virtually constant from the equator to latitude 37° N., it appears improbable that appreciable quantities of water flow northward across the equator in the region for which observations are available.

DISSOLVED NUTRIENT SALTS

Moberg has made a special study of the variations in the amounts of nutrient salts dissolved in the sea water of the Pacific, especially in the region of southern California, and has published one paper which is of particular significance in this connection. It is entitled "The interrelation between diatoms, their chemical environment, and upwelling water in the sea off the coast of southern California." In this paper he shows that between depths of 30 and 50 meters there is, according to counts by W. E. Allen, maximum abundance of diatoms, and above those depths there is decrease in the quantities of PO_4, NO_3, and CO_2, and increase in pH, intensity of light, and temperature. The SiO_2 decreases in quantity toward the surface, but it is peculiar in that there is no significant



SECTION OFF LA JOLLA, CALIFORNIA. SHOWING SUBSURFACE DISTRIBUTION OF SOLUTES. AFTER MOBERG.

change in the trend of its amount above 50 meters. The lower limit of the maximum abundance of diatoms coincides closely with Richardson's measurements of the depth of penetration of light in the region, which is that, at a depth of 50 meters, 98 per cent. of the light of the wave lengths to which the photoelectric cell used by him was sensitive, had already been aborbed. The depletion of PO_4, NO_3, and CO_2 may be attributed to the activity of pelagic plants. The section shows that below a depth of about 50 meters there is an abundant supply of nutrient salts needed by plants. A continuous supply of such substances is maintained by upwelling, which has been the subject of detailed investigations by G. F. McEwen. This work of McEwen's serves as a logical foundation for the later work of Moberg on the distribution of nutrient salts in the sea water of the region.

Moberg, Seiwell, Graham and Paul have published a paper entitled "Phosphate-content of the Surface-water in the Pacific as Related to the Circulation." This paper can not be summarized in this lecture, but it may be pointed out that eastward from Japan to longitude about 130° W., and between latitudes 40° and 10° N. there is in the surface waters of the Pacific a great deficiency in PO_4, the amount being 10 mg or less per cubic meter, and in places there is less than 5 mg per cubic meter. The largest amounts of phosphate are found north of latitude 40° N., off the west coast of the United States, and off the northern part of the west coast of South America and westward from there as far as about longitude 180°. Moberg correlates the surface distribution of phosphate with the circulation of the ocean waters.

SURFACE TEMPERATURES

The first comprehensive studies of surface temperatures of the ocean appear to have been made by Sir John Murray. In one of his papers, entitled "On the Distribution of the Pelagic Foraminifera at the Surface and on the Floor of the Ocean," published in 1897, he reiterates conclusions previously expressed, and says:

The surface of the sea may be grouped into five great zones, *viz.:* (1) A nearly continuous equatorial zone, where the temperature is high and the range throughout the year does not exceed 10° F. This zone includes all the principal coral reef regions. (2 and 3) Two polar zones, where the temperature is low and the annual range does not exceed 10° F. In these zones there are relatively few lime-secreting organisms. (4 and 5) Two regions lying between the equatorial zone and the two polar zones, where a wide range of temperature occurs between the different seasons (annual range amounting to as much as 52° F. in some places). In these temperate regions the secretion of carbonate of lime appears to be much more active in the warmer than in the colder months. It thus appears that the most favorable conditions for lime-secreting organisms are met with in the warm, equable tropical waters of the ocean, and here as a matter of fact we find the greatest development of corals, and the largest number of lime-secreting pelagic organisms. In the polar areas and in the cold water of the deep sea, there is, as is well-known, a feeble development of all carbonate of lime structures in marine organisms.

It should be pointed out that because of the surface circulation of the ocean off the east sides of the continents warm water is carried many degrees northward, that is, until the water comes within the influence of the west wind drifts. This means that, except immediately along the shores where there may be southwardly directed cool currents, conditions are favorable for the growth of organisms that need rather high temperature. In the North Atlantic it is well known that the gulf stream drift continues to the vicinity of the British Isles and that some of its water extends farther toward the north. This warm water tempers the climate of all of northwestern Europe. In the Pacific Ocean the warm waters carried by the Japan current or drift extend eastward to the Alaskan region and then southward until they are off the northwest coast of the United States. This warm water which comes from the west side of the Pacific tempers the climate of the western side of the North American continent from Alaska southward as far as Oregon and California.

The effect of the winds along the west coast of Africa and along the west coast of North and South America in low temperate and subtropical latitudes has already been indicated. These winds, because they blow either along shore or from the land toward the water, produce surface movements of water at 45° to the right of the wind in the northern hemisphere and 45° to its left in the southern hemisphere. To compensate for the water which has been pushed away from the shore there must be an upwelling of cold water, and, as we have already seen from the discussion of the distribution of chemical substances dissolved in sea water, this cold water carries with it substances that are needed for the nutrition of marine plants.

Because of warm water on the west sides of the oceans, reef corals thrive through many degrees of latitude; but on the east sides of the oceans, because of upwelling cold water, they are scarce or absent.

Subsurface Drift of the Water in the Gulf of Alaska

In connection with his study of the distribution of halibut eggs, W. F. Thompson, the director of scientific research for the International Fisheries Commission, needed to know the possibility of the subsurface drift of halibut eggs which are bathypelagic, that is, they float in the water below the level of the surface. In order to find out what the possibilities might be Thompson sought the assistance of McEwen. Thompson acquired the necessary information on the temperature and salinity of the water in the Gulf of Alaska at appropriate depths along several section lines. From the information thus obtained McEwen was able to calculate the relative movements of the water, and he found that there was a rather slow but rather steady subsurface drift toward the northwest and west. This gave to Thompson the information that he needed to understand the drift of the halibut eggs.

Depth of Penetration of Light Into Sea Water

This subject has been studied by numerous investigators, among whom may be mentioned Helland-Hansen, Poole and Atkins, Shelford and Gail, and Burt Richardson. The results obtained by Helland-Hansen by means of a photometer will be summarized. The depth of penetration of light is influenced by latitude. According to Helland-Hansen there would be the same intensity for rectilinear rays, as follows:

In 33° N. latitude at about 800 meters' depth.
In 50° N. latitude at about 500 meters' depth.
In 67° N. latitude at about 200 meters' depth.

The results of experiments made off the Azores on the *Michael Sars* were as follows:

100 meters, red rays weak, blue and ultra-violet strongest.

500 meters, blue and ultra-violet distinctly visible.

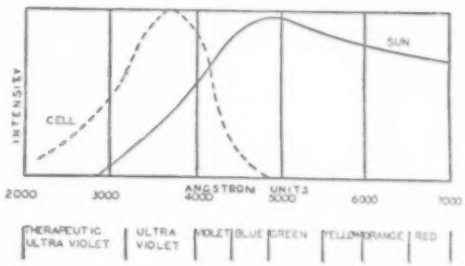
1,000 meters, ultra-violet perceptible.

1,700 meters, no trace of light.

Burt Richardson has summarized and tabulated the results of other investigators, as well as making additional measurements, himself, of the depth of penetration of light. The following is an abstract of a paper by Richardson entitled "The Photoelectric Measurements of the Penetration in Sea Water of Light (Wave-Lengths 2,900 to 4,800 Ångström Units)":

Shelford and Gail in Puget Sound, Washington, and Poole and Atkins in the English Channel off Plymouth, England, determined quantitatively the penetration of light for various depths in sea water by the photoelectric cell method using electrical circuits with high sensitivity. Application of their data and conclusions to an entirely different water, such as the Pacific Ocean near San Diego, California, would not be justified. Therefore, during the summer of 1930, an area seven miles off the coast of La Jolla (City of San Diego), California, was studied by submerging a Burt photoelectric sodium-vacuum cell to various depth levels in the ocean.

The results indicate that about 21 per cent. of the light (of wave lengths 2900 to 4800 Ångström units, to which the photoelectric cell is sensitive) is absorbed by the first ½ centimeter of water, that about 50 per cent. is absorbed by the first meter, 88 per cent. by the first 10 meters, and over 98 per cent. is absorbed by 50 meters of sea water.



Graph comparing sensitivity of photoelectric cell used by Richardson and sunlight. After Richardson.

Richardson has prepared tables giving the results of previous workers, as well as of himself. They are as follows:

Penetration of Light Into Sea Water. English Channel, Plymouth, England. (Poole and Atkins.)
Cell used, Kunz Potassium-hydride; sensitive to wave-lengths, 4,050 Ångströms maximum.)

Date	Depth	Intensity in foot-candles	Per cent. light	Absorption coefficient
1927				
9/7	Surface dry	8,170	100	
				.0035
	5	1,412	17	
				.0029
	10	319	4	
				.0028
	15	76	1	
9/12	Surface dry	4,190	100	
				.0036
	5	1,430	34	
				.0018
	10	581	14	
				.0028
	15	251	6	
				.0014
	20	115	3	
10/3	Surface dry	5,210	100	
				.0027
	5	1,330	26	
				.0010
	10	837	16	
				.0011
	15	493	9	
				.0012
	20	256	5	
				.0019
	25	113	2	

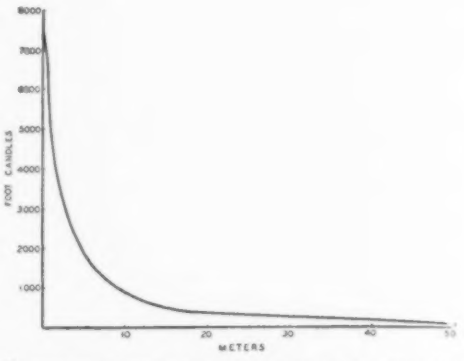
PENETRATION OF LIGHT INTO SEA WATER. PUGET SOUND, WASHINGTON. (SHELFORD AND GAIL.)
(Cell used, Kunz Potassium-hydrogen; sensitive to wave-lengths, 4,200 to 5,000 Ångströms.)

Depth	Intensity in foot candles	Per cent. light	Per cent. wet	Absorption coefficient
Surface dry	8,650	100		
Surface wet	6,550	76	100	
				.00234
5	1,990	23	31	
				.00174
10	830	10	13	
				.0006
25	335	4	5	
				.00049
35	204	2	3	
				.00031
50	129	1	2	

PENETRATION OF LIGHT INTO SEA WATER. OFF LA JOLLA, CALIFORNIA, AUGUST, 1930. (BURT RICHARDSON.)
(Cell used, Burt Sodium-vacuum; sensitive to wave-lengths, 2,900 to 4,800 Ångströms.)

Corrected depths	Per cent. transmitted	Per cent. transmitted from ½ cm water	Absorption coefficient /cm
Surface dry	100		
Surface wet			
½ cm	77	100	
			.0023
5 cm	24	31.9	
			.0015
10	11.5	14.9	
			.0010
15	7.1	8.2	
			.00096
20	5.2	6.8	
			.00042
25	4.2	5.5	
			.0005
30	3.3	4.3	
			.0005
35	2.6	3.4	
			.0003
40	2.2	2.9	
			.0004
45	1.8	2.4	
			.0003
50	1.6	2.1	

It is Richardson's intention, with the assistance of the Southern California Telephone Company, to select a series of photoelectric cells which will be sensitive to other wave-lengths of light than those already studied by him. Although the study is not yet complete, important information has been obtained by the series of investigators as regards the depth of penetration of certain wave-lengths of light, and they are of value in gauging depths to which the photosynthetic activity of plants is effective.



DEPTH OF PENETRATION OF LIGHT, WAVE-LENGTHS 2,900–4,800 ÅNGSTRÖMS, OFF LA JOLLA, CALIFORNIA. AFTER RICHARDSON.

From available present knowledge it is obvious that photosynthesis is confined to relatively shallow depths, probably to 50 to 60 fathoms, 90 to 110 meters, in the tropics, and to shallower depths in latitudes nearer the poles. Professor Stanley Gardiner places the maximum depth of nullipores at 60 fathoms.

CONCLUSIONS

For the circulation of the water in the Pacific we have, as a result of the work of many organizations and more numerous individuals, a working hypothesis. This hypothesis should be tested in all its many ramifications and it should be dealt with according to the findings. Sir Douglas Mawson's expedition in the Antarctic Indian Ocean will certainly throw more light on the interrelation of the water in the Indian Ocean with that of the Atlantic on one hand and that of the Pacific on the other. For the Pacific

basin as a whole there is need for accurate investigation of the water movements according to the modern methods of dynamical oceanography. These methods can not be reviewed here but they are known to all workers in the field of dynamical oceanography. The observations and determinations must be on an extensive scale and, to serve the purpose for which they may be made, they must be precise. Until now only beginnings have been made in the United States, Japan and the Netherlands Indies.

The problems of the chemistry of the ocean will be discussed in this symposium by Messrs. Thompson and Moberg. As yet we have only samples of what may be discovered. These samples excite our curiosity and should stimulate us to make greater efforts to attain a fuller knowledge and better understanding of this complex and fundamental aspect of the Pacific Ocean.

Our knowledge of the depth of penetration of light into sea water is steadily advancing, but it is still far from being adequate.

Although the fundamental elements of the marine environment are physical and chemical, if research stopped with the results obtained in those fields, we should have only partial knowledge of the ocean. There are the organisms and the manifold geologic processes, organic and inorganic, there operative.

The solution of the different kinds of problems stated or indicated requires extensive operations at sea, as well as laboratory work. There has been great activity within the Pacific during the past few years and accounts of it are available in several publications, but there remain areas for the exploration of which there are still no assured provisions, and numerous special problems have been touched scarcely or not at all. Since the chemistry of the sea, organisms as biochemical agents, and the geologic significance of oceanographic research will be discussed by other participants in this symposium, the remainder of my remarks will deal only with completing the exploration of the Pacific basin.

At the third Pacific Science Congress in Tokyo, in 1926, in compliance with an invitation from the President of the Congress, I read a paper, "International cooperation in oceanographic investigations in the Pacific," and at the fourth congress in Java, in 1929, I presented a paper, "Suggestions for oceanographic exploration of the Pacific." The areas in the Pacific for the exploration of which provisions are especially needed are (1) the region adjacent to Antarctica, (2) the area from the Equator to latitude 20° S. and between meridians 130° and 170° W.; and (3) very nearly the whole of the Eastern Pacific from the coast lines of North and South America to a distance of about 2,000 miles offshore. At present we are chiefly concerned with the last-mentioned area.

Before the lamentable destruction of the *Carnegie* it was expected that the Scripps Institution would take over that vessel for two-years' continuous work in the area designated. That plan is now impossible of fulfillment and other means of doing the work must be sought. Some data are already available, but not all are of the required degree of accuracy. Notwithstanding that defect, an endeavor has been initiated at the Scripps Institution to utilize the available data for constructing a longitudinal section for the Eastern Pacific similar to the sections that have already been prepared for the Central and Western Pacific. It is fortunate that the University of Washington has undertaken organized oceanographic research. It and the International Fisheries Commission, perhaps with the assistance of the Canadians and of other organizations in the United States, may undertake investigations in the northern part of the area. The Scripps Institution hopes to

get a vessel, and, if it does, it intends to conduct consecutive work in the area bounded by a line from San Francisco to the Hawaiian Islands, thence southward to the Society Islands, and thence eastward to the South American coast. Although the investigations indicated would not in themselves give a complete picture of conditions in the Pacific, they would make invaluable contributions toward completing that picture, especially after the results have been coordinated with results obtained by others. Perhaps others might be stimulated to fill the gaps for the region adjacent to Antarctica and the Tropical Central Pacific south of the Equator.[2]

[2] Thanks are extended to Mr. John A. Fleming, acting director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for photographs of the drawings which are here reproduced as Figs. 3 to 9, inclusive. All the illustrations used in this paper have previously been published, except Figs. 9, 11 and 12.

THE CHANGED OUTLOOK IN REGARD TO POPULATION, 1831-1931[1]

By Dr. EDWIN CANNAN, M.A., Litt.D., LL.D.
PROFESSOR EMERITUS OF POLITICAL ECONOMY, UNIVERSITY OF LONDON

TIMES change, and economic theories change with them. We need no longer be ashamed of the fact, as we used to be inclined to be in the old days, when our colleagues in other sections of the association professed to despise us for disagreeing among ourselves and perpetually overthrowing conclusions arrived at by our predecessors. We hear less now of the certainty and finality of the other sciences, and can face their exponents unabashed, confident that theories may be useful for leading us on towards the truth without being immutable and exempt from revision.

I think that the biggest change made in economic theory during the last hundred years is to be found in the treatment of the subject of population. In 1831, Malthus was still alive, and quite unrepentant for the shock he had given the public thirty-three years earlier by his "Essay on the Principle of Population as it Affects the Future Improvement of Society." No one, it is true, any longer attached much importance to his doctrine of the inherent incompatibility of the ratios in which it was possible for population and food to increase, but the disfavor with which he regarded what he considered the natural tendency of population to increase was shared by most of the economists of the orthodox school, who had adopted the theory of diminishing returns to agriculture which was evolved in England from the local conditions of the very "short period" of the Napoleonic war.

That theory, not as now taught in a form which makes it innocuous, but as taught in the early years of the nineteenth century, purported to show that the natural limitation of fertile and well-situated land must necessarily mean that the more numerous the people, the more difficult it must be for them to feed themselves. It was admitted that there were counteracting circumstances, summed up as "the progress of civilization," which, in fact, had throughout history prevented the growing population of the civilized world from actually finding it more difficult to feed itself, but these circumstances were regarded as making only temporary headway against the general tendency, and not, like it, as being a law of nature. J. S. Mill, in his "Principles of Political Economy with Some of Their Applications to Social Philosophy," which, though not made into a book until seventeen years after, was really thought out before 1831, and represents the ideas of 1800 to 1830 better than any other work, even ventured to assert that though the people of his time were better off than the people of a thousand years before, they would have been still better off if the increase of population had been less.

The economic history of the hundred years has tended to bring about a very complete reversal of economists' view of this matter.

The hundred years began with developments which threw great discredit on the fundamental assumption of the old school that the extension of human occupation of land necessarily meant that less fertile and less well-situated land must be occupied as numbers grew. It was easy for men who saw arable cultivation creeping over barren

[1] A lecture delivered at the centenary meeting of the British Association for the Advancement of Science, London, September, 1931.

hills in England and stony "bogs" in Ireland to believe in that theory when Chicago was a collection of Indian huts, and Broadway, New York, a rough cart track to a farm, but the application of steam to ships and railways enabled mankind to extend easily over an immense area of land more fertile than much of what was occupied before. And as for situation, not only did the improvement in transport, coupled with the violations of natural geography involved in the cutting of the great ship canals, bring the "more distant" lands nearer the "market," it also eventually brought "the market" to the "more distant" lands.

So we no longer think of the first cradle of the human race (or the first cradles of the human races if there are more than one) as the most fertile and well-situated spot (or spots) from which men have gradually been forced outwards. You all probably know the opinion of the British Army in Mesopotamia, expressed by the sergeant who was told by an officer that he was now on the very site of the Garden of Eden: "Well, Sir, all I can say is that if this was the Garden of Eden it's no wonder the twelve apostles mutinied." Though the sergeant was evidently not a well-read man, the change of view had reached even him.

Later in the hundred years, scientific discovery in various directions has led to a complete change of emphasis in regard to the importance of what the old economists used to call "improvements." The old economists thought of hedges and ditches, drains, and a few other trifles of that kind which would enable corn to be more easily produced from European fields, and just a little of better breeding of cattle and sheep. These were things which might, they believed, interrupt for a time, now and then, the general downward drift of the returns to agricultural industry, but could not do more than that. Modern science has changed our outlook. We set no bounds to the possibilities of improvement. We expect to make unwholesome areas healthy, and to modify vegetable as well as animal products so that they will better serve our needs. Primitive mankind presumably fought and killed some of the now extinct carnivora; advanced mankind fights and will kill the locusts and the smaller insects which have hitherto prevented much use being made of some of the most fertile areas of the world. It was not an economist who, only a few years ago in the presidential chair of the association, foretold that very soon the world would be suffering from a shortage of wheat.

Thus, even if we still expected population to increase very rapidly, we should not believe, as J. S. Mill did, that it "everywhere treads close on the heels of agricultural improvement, and effaces its effects as fast as they are produced."[2] But in fact, Cotter Morison's cry, made only a generation ago, that all would be well if only we could stop for a few years "the devastating torrent of babies" now seems grotesque, for we do not now expect rapid increase of population to continue much longer, even if it becomes progressively easier to obtain subsistence.

The approach of reduction in the rate of growth of population began to show itself in England in the second half of the 1871–80 decade, when the annual number of births became nearly stationary after the rapid increase recorded down to 1876. But the public takes little notice of the supply of people furnished by the births. Just in the wooden way in which illiterate farmers and unbusinesslike old ladies look at their balances at the bank, so the public looks at the censuses. The census of 1881 showed an increase of 14.36 per cent. in the decade, which was higher than that shown by any of the censuses except those of 1821

[2] "Principles," Bk. IV, ch. iii, § 5.

and 1831, which were probably unduly swollen by the diminishing incompleteness of the enumerations. In 1881–91, in spite of high emigration, the rate of increase only dropped to 11.65 per cent., so rapid increase of population was still regarded as the normal thing which every one should expect. The Royal Commission on the Water Supply of the Metropolis in 1893 deliberately rejected the reasonable suggestion that the rate of increase in Greater London might continue to fall as it had already begun to do, and relying on a continuance of observed increase, put the probable population in the present year, 1931, two and three quarter millions more than the recent census has shown it to be.

But I had noticed that the old rapid increase in the annual number of births seemed to have come to an end, and working on the ages of the people as recorded in successive censuses, I put before this section of the association, at its meeting in Ipswich in 1895, a paper (subsequently published in the *Economic Journal* for December in that year) in which I estimated the number of persons who would be living at each census up to that of 1951 on the assumption that migration, mortality and the absolute number of births (not the rate) remained stationary. I found that on these hypotheses the population of England and Wales would stop increasing during the present century, and would have only a trifling increase after 1941. The paper suggested that this was, at any rate, not improbable.

Hostile critics derided what they called my "prophecy," and for some time events were unfavorable to me. Emigration fell off enormously, mortality decreased, and the births increased slightly, so that the census of 1901 showed an increase of 12.17 per cent. in the decade, the absolute increase of three and a half millions being the largest recorded. But the situation was not fundamentally altered, since the increase of births was due entirely to the drop in emigration, which had caused a larger proportion of persons of parental age to remain in the country. In the *Fortnightly Review* of March, 1902, I returned to the charge with an article on the "Recent Decline of Natality in Great Britain," in which, using a method of weighting the annual numbers of marriages by their proximity to the births recorded for each year—a method which seems to have been beneath the notice of the mathematical statisticians of that period—I was able to show, I think, conclusively, that the number of children resulting from each marriage was falling steadily and rapidly, and insisted with more emphasis than before on the "considerable probability of the disappearance of the natural increase of population—the excess of births over deaths—in Great Britain within the present century."

The decade 1901–11 was indecisive; the ratio of increase was smaller than in any of its ten predecessors, but the absolute amount of increase just topped that of 1891–1901, and the number of births till 1908 or 1909 seemed to indicate some recovery of natality. But this was illusory. Even before the war the births had got down again to the level of 1876. The war sent them tumbling down to about three quarters of that number, and now, after a wild but very short-lived recovery when the army returned from abroad, they seem inclined to settle at the war figure—three quarters of the number attained more than fifty years ago when the total population was twenty-six millions instead of forty millions, as it is now. The ratio of births, legitimate and illegitimate, to my weighted figure of marriages was just over $4\frac{1}{2}$ fifty years ago, fell gradually and steadily to $3\frac{1}{4}$ before the war caused it to collapse.

It was commonly supposed by many of those to whom percentages serve rather to hide than to expose the facts

on which they are based, that the diminution of births was being counterbalanced by the decline of infant mortality. It is true of course that diminution of infant mortality mitigates the effect of decline of natality, but the degree in which it can do so obviously decreases as the rate of infant mortality falls. When that rate is 500 per thousand, as it probably was here in the reign of Queen Anne, and may be still in great parts of Africa, a cutting down of births by 25 per cent. can be counteracted completely by a drop of one third in the infantile mortality rate. But when the infant mortality rate is down to 100 per thousand, it would have to fall to nothing at all in order to counteract a decline of only 10 per cent. in the number of births. In fact, the rate has fallen in England and Wales from about 140 to about 70 in the fifty years from 1881, and this drop to one half only balances about one fifth of the decline in the number of births.

Though there were eminent dissentients only a few years ago, statisticians are now agreed that in the absence of some great and unexpected change, the increase of population in England and Wales will come to an end af a very early date. Even the lay public has been to some extent enlightened and rather shocked by the recent census announcements that the population of Scotland has actually decreased in the ten years, and that of England and Wales has increased only 2,061,000, as against 3,543,000 in the ten years from 1901–11, though the emigrants have been 324,000 less.

The same change is observable in some degree in other Western European countries and our own oversea offshoots. The cause of it—birth control—will doubtless in time affect the rest of the world, so that while we may expect considerable increase—even an increase much more rapid than at present owing to decrease of huge infant mortality—to take place among the more backward peoples for another half-century at least, there is no reason whatever for expecting the population of the world to "tread close on the heels of subsistence" in the future, even if it may be correctly regarded as having done so in the past.

This change in our expectations involves many changes of emphasis, both in the theory of production and in that of distribution.

Two of them are perfectly obvious. First, the need, which J. S. Mill and most of his contemporaries and immediate predecessors felt so strongly, for insisting on the due restriction of population, has completely disappeared in the Western countries. Economists do not now require to talk as if the first duty of men and women was to refrain from propagating their race. Secondly, the need for insisting on the desirability of saving has become less pressing. A rapidly increasing population requires a rapidly increasing number of tools, machines, ships, houses and other articles of material equipment in order merely to maintain, without improving, its economic condition, while at the same time the maintenance of a larger proportion of children renders it more difficult to make the required additions. To a stationary population saving will still be desirable for the improvement of conditions, but it need no longer be insisted on as necessary for the mere maintenance of the existing standard.

But there are other changes of equal importance which are more likely to be overlooked. One is in regard to the weight which we attach to the different kinds of production. In the middle of the eighteenth century "subsistence," and what we should consider a very coarse and inadequate subsistence, probably seriously deficient in vitamins, appeared so much the most important economic good that the French *Économistes* insisted on calling all labor which did not get something out of the soil *stérile*

or barren; and our own Adam Smith, with all his common sense, while admitting the manufacturing class into the ranks of "productive" laborers, insisted on excluding domestic servants, physicians, guardians of law and order, and all other workers who did not make up material objects, or who were not employed for profit (he never was quite sure which criterion he meant to stand by). The great Christian philosopher, Paley, believed that nothing more than a "healthy subsistence" was required for perfect happiness. Even Malthus and his immediate disciples, when they insisted on the desirability of the working-class having a high standard of comfort, seem to have done so more because this would prevent the "misery" of semi-starvation for adults and absolute starvation for infants than because there is a direct advantage in being comfortable. Ricardo said "the friends of humanity cannot but wish that in all countries the laboring classes should have a taste for comforts and enjoyments," not apparently because comforts and enjoyments are good in themselves, but because "there cannot be a better security against a superabundant population," the population being superabundant, in his opinion, when it is subject to famine.

All this emphasis on food is now out of date. We no longer look forward to a future in which an increasing population will be forced by the operation of the law of diminishing returns to devote a larger and ever larger proportion of its whole labor force to the production of food. We know that even in the past, with a rapidly increasing population, the returns to agricultural industry have increased so much that civilized mankind has been able to feed itself better and better, while giving a smaller and ever smaller proportion of its whole labor force to the production of bare subsistence; and we can reasonably expect that the increase in the productiveness of agricultural industry will be at least as great in the future, so that under the combined influence of the "narrow capacity of the individual human stomach" and the stationary number of stomachs, not only a smaller and ever smaller proportion, but a smaller and smaller absolute number of workers will be able to raise food for the whole.

Even the politicians, who for the most part follow the economists with a sixty or seventy years' lag, are beginning to realize the change, and are losing their enthusiasm for schemes for "settling more people on the land," either in colonies or at home, and thereby increasing the already excessive depreciation of agricultural compared with manufactured products. The numerous subsidies which they still give to agriculture are mostly of an eleemosynary character intended to relieve distress, and the encouragement which they give to agricultural production is only an incidental effect, unintended and often deplored. They are defended, not on the ground that they increase food, but because they are supposed to increase employment.

The necessary change of emphasis applies not only as between food and other things, but as between most primary and most finishing industries. In face of rapidly growing knowledge and slowly growing or stationary population, it is inevitable that the "staple" or "heavy" industries which provide materials should decline relatively to those which provide finished goods and services. The demand for each of such things as pig-iron and yards of cloth is easily satiated; and so also, no doubt, is the demand for cricket-bats and chauffeurs. But the minor or "lighter" industries are susceptible of an indefinite multiplication which makes the demand for their products, taken as a whole, insatiable. Increase a person's power of spending, and he will not increase his purchases in weight or bulk so much as in refinement of form, so that a richer people will devote a less proportion of their labor to

producing things like pig-iron and bricks. Moreover, the mere fact of the disappearance of rapid increase of population tends to increase the proportion of demand which can be satisfied from scrap without fresh primary production. So, given a stationary population with rapidly increasing knowledge applied to production, we may expect the already observable tendency towards a less proportion of the whole labor-force being employed in the "heavy industries" and a larger in the lighter industries to become more pronounced. Perhaps we see this even now in the slight drift of industrial population from the North to the South of England which appears to be taking place.

Another change of emphasis, of little importance on the Continent, where the West-Ricardian theory of rent never took real root, but of great importance in England and other English-speaking areas, is in respect of the landowners' share of the community's income. The disappearing bugbear of diminishing returns carries away with it the vampire rural landlord, who was supposed to prosper exceedingly when diminution of returns made food scarce and dear. You all know the famous passage in which J. S. Mill described the landlords as they appeared to him and the school which he, a little belatedly, represented:

> The ordinary progress of a society which increases in wealth is at all times tending to augment the incomes of landlords; to give them both a greater amount and a greater proportion of the wealth of the community, independently of any trouble or outlay incurred by themselves. They grow richer, as it were, in their sleep, without working, risking, or economizing.[3]

Perhaps the disciple went a little beyond his master, Ricardo, in asserting so roundly that in a prosperous society the landlords must tend to get a larger and ever larger *proportion* of the whole income, but there can be no doubt that this was the impression which the Ricardian school conveyed to the public, and which formed the foundation for Henry George's scheme of land nationalization and the agitation for land-value taxation. If the school had only meant to teach that the land became more valuable absolutely—in the sense of being worth a larger absolute amount of commodities rather than a larger proportion of all the commodities and services constituting the community's income—they could not have supposed land so peculiar, since it would share this characteristic with many other things—with anything which was more limited in supply than the generality.

To grasp the completeness of the change of view which has taken place in the last hundred years, we must notice that Mill and the whole school which he represented were thinking not of the few lucky landlords who have inherited land which has been selected by nature or accident as the site of a city, but of the ordinary rural agricultural landlords. So far have we moved that the land-value taxers of to-day quite cheerfully propose to exempt all "purely agricultural value" from the imposition which they advocate.

Envy of the happy owners of such urban land as rises in value more than enough to recoup what they and their predecessors in title paid in road making, sewering and other expenses of "development" plus loss, if any, in waiting for income, still plays a part in contemporary politics, but the economist foresees that there will be at any rate less of such rise of value when the adult population ceases to increase and the demand for additional houses and gardens consequently disappears. He realizes that if any such rise continues, it will be due to the people being not only able, as they doubtless will be, to occupy a larger area with their houses and gardens, but also desirous of doing so. He will think this quite possible, but will not be confident

[3] "Principles," Bk. V, ch. ii, § 5.

about it, when he reflects that the vast spread of villadom may be only a temporary phenomenon, and that the married couples of the future, childless or with small families, may be more content with flats in towns and little bungalows with tiny curtilages right in the country.

The disappearance from economic theory of the picture of the vampire landlord taking an ever-increasing proportion of the whole produce of industry which was itself decreasing per head of workers, leaves the theoretic arena open for discussion of the sharing of the whole produce between earnings of work and income derived from possession of property of all kinds.

As to this, the economists of a hundred years ago had nothing to say. If they thought of the question at all, they mixed it up hopelessly with the rate of interest on capital, imagining property to receive a smaller proportion when the rate of interest fell, and *vice versa*. The Socialists, who followed them in fact the more closely the more they denounced them, failed completely to clear up the confusion, and it dominates the mind of the lay public even now—much, I admit, to the discredit of the economists, who should have taught that public better.

While there are no statistics on the subject worth much, and none covering any considerable area either of place or time, past history is sufficiently known to assure us that increasing civilization has, in fact, made the aggregate share of property grow faster than that of labor, the obvious cause of this being that useful things constituting property have grown faster than population, and so much faster that what decline of the rate of interest has taken place has not been sufficient to counteract the tendency. The most primitive people had scarcely any tools, and their buildings, if any, could be erected in a few hours. Ownership certainly did not then give a claim to about one third of the whole income, as statistics suggest that it does in modern western countries.

There is nothing to show that this tendency will be either reversed or intensified by a cessation of the growth of population. The cessation will, of course, tend to reduce the desirability of additional equipment; a large part of the additions of the past have been required simply to enable the additional people to be provided with tools, houses and other instruments of production or enjoyment. But additions to equipment will be made with less sacrifice of immediate enjoyable income than before, so that the increase of quantity may be sufficient to counteract the decline in the value of the units. Moreover, it is quite impossible to say what the tendency of invention may be in the future—whether to enhance or to diminish the value of additional material equipment.

But the history of the last hundred years suggests that this question of the division of income between property and labor is losing whatever importance it possessed. The economists and socialists of a hundred years ago were little removed from the time when it was common to talk of "the laboring poor," as if society was pretty sharply divided into poor workers on the one side and rich owners of property on the other. There were, indeed, some members of the propertied classes who were poor, but they were offshoots of the wealthier families rather than members of the proletariat with a little property. How innocent the mass of the people were of the crime of owning anything you may realize if you recollect that none of the agencies with which we are familiar for enabling them to invest had then got beyond the embryo stage. Friendly societies, cooperative societies, building societies, savings banks, are all modern growths. Before their advent a worker could, of course, become a small master —never, I think, a small mistress—and from a small master grow to be a big master, but if, for any reason this was not open to him, what could he do with savings, supposing he was able to make

any? Put them in a stocking, or the thatch, or under the garden soil, and if they happily escaped accident there, and accumulated sufficiently, give them to an attorney of doubtful honesty to be lent out on mortgage. I remember only about fifty years ago being told by a booking-clerk at a moorland station, about a hundred miles from London, how two old women had recently paid for return tickets to London in threepenny-bits, and by a solicitor that an old man from the same district had just brought him for investment on mortgage a large sum in gold which he had so far been keeping in the thatch of his cottage. All this is now changed, and when property, as a whole, and not merely the large property-owners, is attacked, the great investing agencies of the "working classes" become formidable opponents and are supported by the small direct investors who have been helped by them.

And while many of the working-class have become property owners, many of the propertied class have become the paid servants of public companies and other institutions, so that the old sharp distinction between the wage-earner and the capitalist is become a thing of the past, and the division of income between property and labor is no longer a division between two classes composed of different individuals, but a division between two sources of income largely possessed by the same individuals.

Thus, in distribution, emphasis on the old categories of land, capital and labor is rapidly becoming obsolete and is being replaced by emphasis on individual riches and poverty, however arising. No longer do we think of relieving poverty by improving the terms of the general bargain which theory conceives labor as making with capital; we are much more likely to meet with arguments that individual poverty is being caused by this general bargain being too much in favor of the wage-earners. It is no longer the lowness of standard earnings that worries the philanthropic economist, but the fact that so many people are unable to rank themselves among recipients of those wages. Emphasis is on unemployment.

Unemployment is not really a very modern phenomenon. The crowds of beggars who collected their daily dole in the Middle Ages from the monasteries and from private wayfarers and householders were, perhaps, as large a proportion of the population as the normal registered unemployed of to-day. The "distresses" of the period just preceding a hundred years ago seem to have been accompanied by enormous unemployment, but we have no reliable statistics, and the loose statements, such as that in Birmingham in 1817 one third of the workpeople were wholly unemployed and all the rest on half-time, do not help us much. But so far as I know, it has never been contended that history shows unemployment to be greater when population (or even population of working age) is rapidly increasing.

Yet it is common to talk of "the difficulty of providing employment for a rapidly increasing population," and some eminent authorities quite recently endeavored to console the public by alleging that the coming decline in the growth of numbers will greatly alleviate the present situation in regard to unemployment.

I believe this to be a profound error, based on an elementary misconception of the origin of demand. The old proverb, "With every mouth God sends a pair of hands," is true and valuable, but no more so than its converse, "With every pair of hands God sends a mouth." The demand for the products of industry is not something outside and independent of the amount of products. The demand for each product depends on the supply of products offered in exchange for it, and the demand for all products depends on the supply of all products. Consequently, there is not the slightest

danger of the working population ever becoming too great for the demand for its products taken as a whole.

Unemployment arises not from insufficient demand for the products of industry as a whole, but from the number of persons offering to work in particular branches of industry being in excess of the number admissible, having regard to the conditions and wages which are required to satisfy both the would-be workers who are unemployed and the persons already in employment. If the unemployed will not take what employers would offer them, the case is simple, and it is only a little more complicated if they are willing to take, and the employers are willing to give, something less than what is paid to the persons already employed; but the two parties are prevented from coming to terms on that basis by the fact that those already employed would go out on strike if the additional contingent was accepted at a lower rate than that which they themselves are receiving.

Now one of the commonest causes of such a situation is a falling off of demand for the products of a particular branch of industry. The fact that the demand for any product, let us say coal, for example, falls off, is a good reason for fewer persons being employed in that branch of industry and more in other branches. If the diminution of demand is very gradual, the necessary reduction in personnel can be effected by a cessation of recruiting. Many a branch of industry has gradually wilted away in this manner without much inconvenience or hardship to any one. But if the diminution is more sudden, unemployment results owing to the natural reluctance of persons skilled, or at any rate experienced, in the particular branch of industry to leave it and try for employment in some other. The thoughtless outsider is apt to say that both the unemployed and those who are still employed in the branch should accept lower wages, and so by cheapening the product, extend the demand for it. As a temporary palliative this may sometimes be reasonable, but it is evidently never the best final solution of the difficulty. It is not reasonable that a trade should be continuously worse paid than others merely because the demand for its products was once bigger than it has become. What the diminution of demand calls for is a redistribution of labor force, fewer persons being allotted to the branch of industry of which the products are less in demand, and more persons to the other branches.

But when population is increasing, absolute diminutions of demand are likely to be somewhat fewer, and somewhat less acute when they do occur, than when population is stationary. If, for example by the introduction of oil, or more economical consumption, the average person's demand for coal is reduced by one tenth, in a stationary population the total demand for coal would be reduced by one tenth; but if the population in the same time increased 12 per cent., the total demand would be not reduced but slightly increased, and there would be no employment difficulty.

We ought therefore not to imagine that a stationary or declining population will rid us of the trouble of unemployment. It will provide more rather than less reason for promoting mobility of labor in place and occupation, and we shall have to take more care, rather than less, than at present to secure that arrangements, which seem superficially desirable, do not hinder that mobility.

It is inevitable, I suppose, that the question will be asked, whether cessation of the growth of population is to be regarded as a good or an evil turn in human history. But the limitations of economics and perhaps of human nature prevent any straight answer being given. Nationalists in each nation want their own nation to increase in comparison

with others; if they think of the others' interest at all, they say and believe that it will be promoted by the predominance of their own nation. We can get no further that way, since the pretension of each is contradicted by the pretensions of the others. If we try to avoid this obstacle by saying that we will ignore national and racial differences, and assume either that somehow the generally fittest will grow at the expense of the others, or that each as well as the whole will have stationary numbers, we still have to face the fact that our conception of the distinction between economic welfare and welfare of other kinds is nebulous in the extreme, and that if it was clearer, we should not know—I think we never can know—how much of the one should be regarded as equal to a given quantity of the other.

Different persons will give different answers. Some agree with Paley that ten persons with sufficient subsistence must be in possession of more welfare than a single millionaire; others with J. S. Mill that the world turned into a "human anthill' would be an undesirable place of residence. The same person will give different answers according to his mood at the moment. Personally, I spent my early boyhood in a town which throughout my life has been the most prosperous in England, and I have long lived in another which, having added motor manufacture to education in its old age, has lately been growing nearly as fast, and sometimes when I contemplate their growth I feel a little like G. R. Porter when he wrote the "Progress of the Nation," during the period 1800 to 1831. At other times, and I think more often, I regret the open heath and the untouched pine wood which stretched in my early recollection to within a few hundred yards of the Bath Hotel at Bournemouth, and I hate the gasworks straddling the river and the bungalows shutting in the main roads out of Oxford; then I agree with Mill that it is well that population should become stationary long before necessity compels it.

After all, the increase must stop some time, and watching the effect of the stoppage will be a very interesting experience which I should like to have been born late enough to enjoy.

THREE HUNDRED YEARS OF TOM THUMB

By Dr. HARRY B. WEISS

NEW BRUNSWICK, N. J.

At the outset, I may as well admit that I have no intention, in this account, of tracking the story of Tom Thumb to its lair. Although this has been attempted by various learned men, the results are not always satisfying. Dr. Johnson, it is said, once "withdrew his attention" from a great man who bored him and "thought about Tom Thumb." Without seeming to place myself in such distinguished company, perhaps I too may be permitted to say that my thoughts about Tom Thumb are the result of boredom, or if you prefer, idle curiosity.

Although I am concerned here mainly with the changes which have taken place in the version during the past three hundred years, it seems necessary to mention briefly a few facts and dates relating to early information about Tom Thumb. Reginald Scot, in his "Discoverie of Witcheraft," printed in 1584, speaking "Of vaine apparitions, how people have beene brought to feare bugges," mentions "Tom thombe" along with the giants, imps, fairies, satyrs, witches, goblins, etc., with which "in our childhood our mothers maids have so terrified us." And Thomas Nashe in "Pierce Penilesse His Supplication to the Diuell" (1592) grumbles that "eury grosse braind Idiot is suffered to come into print, who if hee set foorth a Pamphlet of the praise of Pudding-pricks, or write a Treatise of Tom Thumme, or the exploits of Vntruss; it is bought vp thicke and threefold, when better things lie dead."

In 1621 the tale appeared, in prose, in Richard Johnson's "The History of Tom Thumbe the Little, for his small stature surnamed King Arthur's Dwarfe: Whose Life and aduentures containe many strange and wonderfull accidents, published for the delight of merry Time-spenders." Tom Thumb also appears in Drayton's "Nymphidia" (1627) and it would be possible to mention other notable instances where Tom Thumb has been utilized to advantage, such as Fielding's burlesque, "Tom Thumb A Tragedy" (1730) and Kane O'Hara's "Tom Thumb; A Burletta, Altered from Henry Fielding" (1830).

The earliest Tom Thumb in Europe appears to be the Thaumlin or Little Thumb of the Northmen, a dwarf of Scandinavian descent. The popular Danish history of Svend Tomling treats of "a man no bigger than a thumb, who would be married to a woman three ells and three quarters long." Then there is the "Daumerling," a little Thumb of the Germans, who is swallowed by a dun cow. It is said that the German and Danish "Thumb" stories contain much that is found in the northern versions. In India Tom Thumb has his counterpart in the Khodra Khan of the Mohammedans. In the Hindoo story, Vamuna is so tiny that he thinks the water-filled impression of a cow's hoof in the earth is a lake and he begs King Mahabali for a piece of ground over which he may walk in three strides.

Tom Thumb, a comic story, belongs to one of the groups or divisions of the so-called Swallow cycle. The hero is swallowed by a cow, a giant, a fish, a miller and a salmon, and escapes from all in safety. According to Macculloch, many swallow myths gradually change into stories which attempt to account for various natural events. The curiosity of man makes him invent stories ex-

plaining such events. Or an inventive story-teller might build upon an old myth. Many folk-tales of various countries have been changed and modified during the passage of centuries, yet they retain some common characteristics and enough of their antiquity to identify them as the remains of beliefs, customs and ideas of a forgotten age.

In this account, however, we shall not go back beyond the 1630 edition of Tom Thumb, which was bequeathed to the Bodleian Library by the author of the "Anatomy of Melancholy." This small black letter edition bears the title "Tom Thumbe, his life and death: wherein is declared many maruailous acts of manhood, full of wonder, and strange merriments. Which little knight lived in King Arthurs time, and famous in the court of Great Brittaine. London, printed for John Wright. 1630." The ballad, consisting of 135 lines, opens as follows:

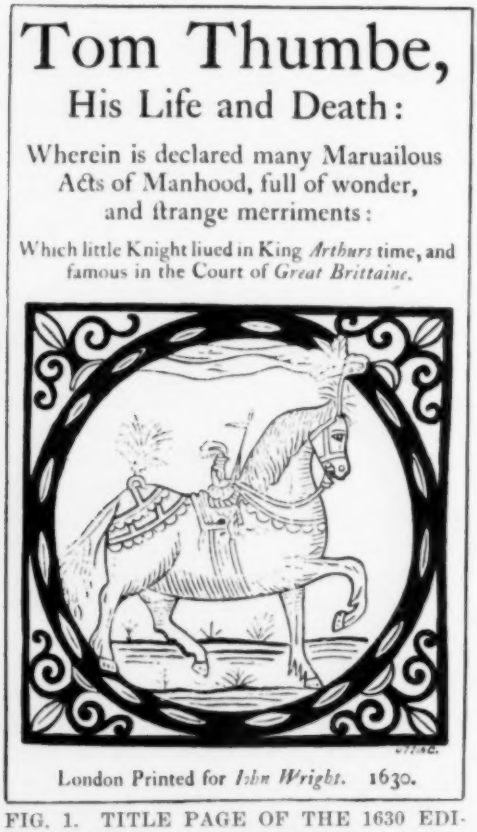

Tom Thumbe,
His Life and Death:
Wherein is declared many Maruailous Acts of Manhood, full of wonder, and ſtrange merriments:
Which little Knight liued in King *Arthurs* time, and famous in the Court of *Great Brittaine.*
London Printed for *Iohn Wright.* 1630.

FIG. 1. TITLE PAGE OF THE 1630 EDITION OF "TOM THUMBE" SHOWING TOM ON KING ARTHUR'S HORSE.

FIG. 2. TOM THUMB'S MOTHER (1630 EDITION).

In Arthurs court Tom Thumbe did Liue,
A man of mickle might,
The best of all the table round,
And eke a doughty knight:

His stature but an inch in height,
Or quarter of a span;
Then thinke you not this little knight,
Was prou'd a valiant man?

His father was a plow-man plaine,
His mother milkt the cow,
But yet the way to get a sonne
"This" couple knew not how,

Until such time this good old man
To learned Merlin goes,
And there to him his deepe desires
In secret manner showes,

How in his heart he wisht to have
A childe in time to come,

FIG. 3. TOM THUMB'S FATHER (1630 EDITION).

To be his heire, though it might be
No bigger than his Thumbe.

Merlin told the plowman that his wish would come true and Tom was eventually "begot and borne in halfe an houre" and in four minutes he grew as tall as the plowman's thumb. Of course he was under the protection of the fairies, and at his christening, which was attended by the "Fayry-Queene" with her "traine of Goblins grim," he was named Tom Thumb. Little is told of his early childhood. The fairy queen clothed him in garments which lasted many years, a hat made of an oak leaf, a shirt of a spider's web, his hose and doublet of thistle down, his garters, two little hairs pulled from "his mothers eye" and his boots and shoes from a mouse's skin. Thus attired he sallies forth to play with the neighboring children, losing his "cherry stones," stealing a fresh supply from his playmates, indulging in such tricks as hanging "Black pots, and glasses vpon a bright sunnebeame," and laughing at the whippings which the other boys received when their attempts to do the same ended in broken crockery. Because of the turmoil which Tom created when he went out to play, his mother kept him at home, and from then on his adventures commenced in earnest.

He sate vpon the pudding-boule,
The candle for to hold;
Of which there is vnto this day
A pretty pastime told:

For Tom fell in, and could not be
For euer after found,

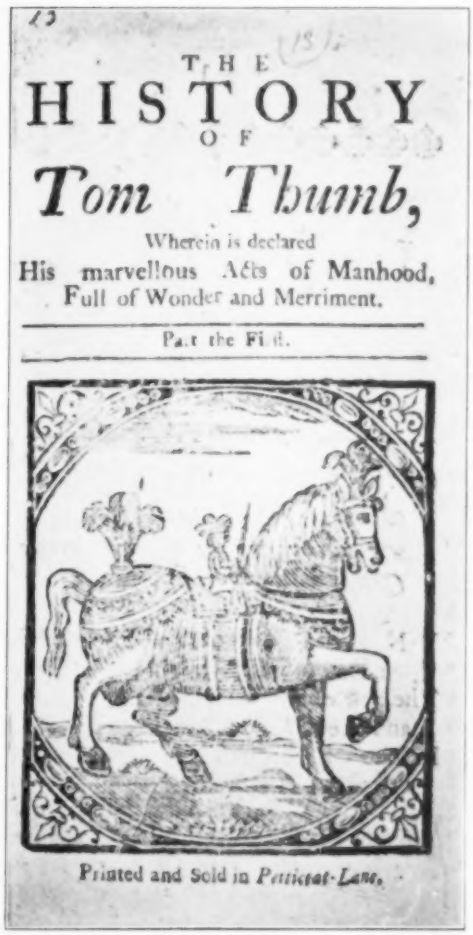

THE
HISTORY
OF
Tom Thumb,
Wherein is declared
His marvellous Acts of Manhood,
Full of Wonder and Merriment.
Part the First.
Printed and Sold in *Petticoat-Lane.*

FIG. 4. TITLE PAGE OF A PETTICOAT LANE EDITION OF TOM THUMB.

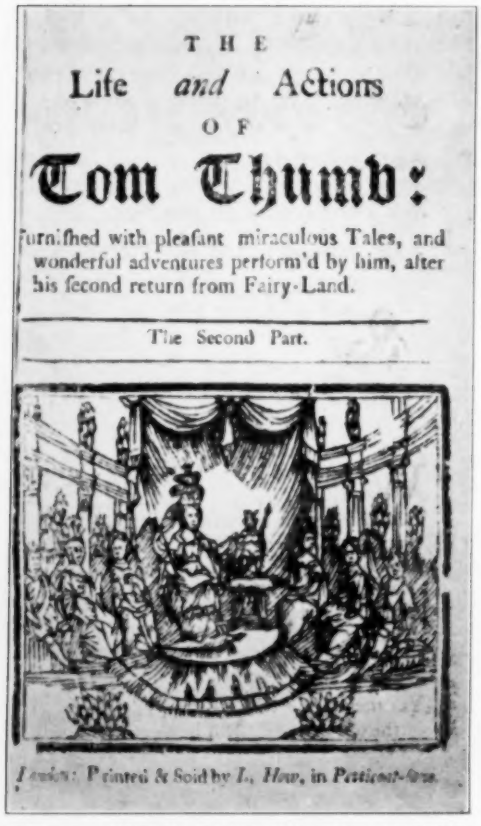

THE
Life *and* Actions
OF
Tom Thumb:
furnished with pleasant miraculous Tales, and wonderful adventures perform'd by him, after his second return from Fairy-Land.
The Second Part.
London: Printed & Sold by *L. How*, in *Petticoat-Lane*.

FIG. 5. TITLE PAGE OF THE SECOND PART OF THE PETTICOAT LANE EDITION.

For in the blood and batter he
Was strangely lost and drownd.

Although his mother searched long, it was in vain, and unknowingly she thrust her son into the pudding and the pudding into the kettle. But the pudding bounced around so violently that she thought the devil was inside and very charitably she bestowed it upon a passing tinker. Tom's voice issuing from the pudding scared the tinker so that he threw it down and ran. Tom then emerged and returned home, but only to get into fresh trouble. When Tom's mother went to milk her cows, she tied him fast to a thistle so that the blustery wind would not blow him away, but alas, a cow came by and ate the thistle, Tom and all, and Tom traveled the entire length of the cow's alimentary canal. His next escapade happened while he was helping his father plow. He fell into the furrow, was carried away, just like a grain of corn, by a raven and

Unto a giants castle top,
In which he let him fall,
Where soone the giant swallowed vp
His body, cloathes and all.

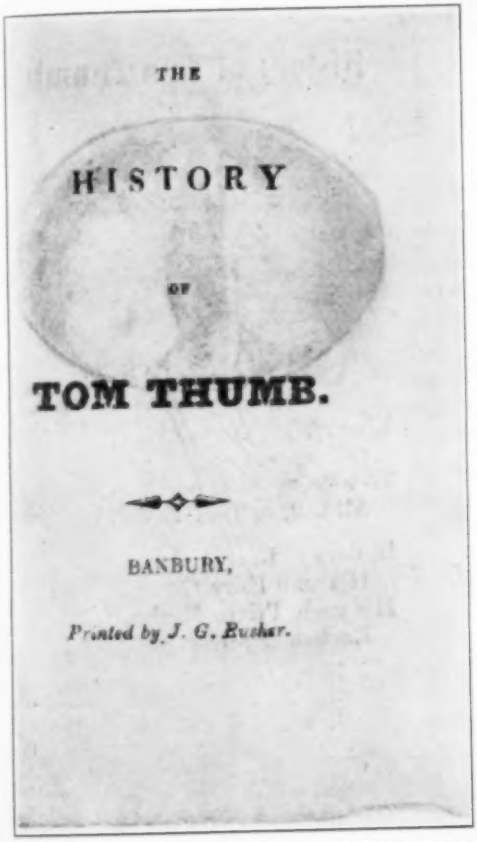
But in his belly did Tom Thumbe
So great a rumbling make,
That neither day nor night he could
The smallest quiet take,

Until the gyant had him spewd
Three miles into the sea,
Whereas a fish soone tooke him vp
And bore him thence away.

The Famous History of
TOM THUMB
Wherein is declared,
His Marvellous Acts of Manhood
FULL OF WONDER AND MERRIMENT
PART THE FIRST.
PRINTED AND SOLD IN ALDERMARY CHURCH YARD, LONDON.

FIG. 6. TITLE PAGE OF AN ALDERMARY CHURCH YARD EDITION OF TOM THUMB.

The fish was caught and sent to King Arthur. Tom was discovered and enjoyed high favor at court. He danced a "galliard braue vpon his queenes left hand," went on hunting trips with the king, paid a visit to his parents, who feasted him three days on a hazel nut, and returned to King Arthur's court where he engaged in tournaments, vanquishing all his opponents to the great


THE

HISTORY

OF

TOM THUMB.

BANBURY,

Printed by J. G. Rusher.

FIG. 7. A BANBURY EDITION OF TOM THUMB.

amazement of the knights, but as a result of such strenuous exertions finally becoming sick, and dying, in spite of the skill and cunning of King Arthur's physician.

And so with peace and quietnesse
He left this earth below;

FIG. 8. TOM DANCING A GALLIARD UPON THE QUEEN'S LEFT HAND (ALDERMARY CHURCH YARD ED.)

And vp into the Fayry Land
His ghost did fading goe.

He was received by the Fairy Queen "with musicke and sweet melody" and King Arthur, after mourning with his knights for forty days, built a "tomb of marble gray," "in remembrance of his name."

Thus ends what appears to be the original tale of Tom Thumb, but the story was amplified by the addition of a second and third part, both detailing fresh adventures but lacking the charm and quaintness of the original version. Hazlitt has stated that the author of these later parts was "not trammelled by rhythm, grammar or geography." The second part commences with Tom's return from fairyland and his fall

FIG. 9. "NOW BY A RAVEN OF GREAT STRENGTH AWAY POOR TOM WAS BORNE."
(ALD. CH. YD. ED.)

"into a pan of firmity," in good King Edgar's court, causing the cook to drop the pan and mess things up generally. Tom was dragged over to the king's table, where

> With clubs and staves, forks and prongs,
> He guarded was, unpitied,
> To answer for the mighty Wrongs,
> Which he had there committed.

Just as they began to vote on what form his death should take, Tom escaped from such an unfriendly atmosphere by jumping down a miller's throat and in addition to whistling, singing and dancing,

> Tom often pinch'd him by the tripes,
> And made the Miller roar,
> Alas! alas! ten thousand stripes
> Could not have vex'd him more.

After calling in the doctor and twenty learned men and after confessing to various thefts, the miller jumped in a river "and turn'd Tom Thumb into the tide," where he was swallowed by a salmon which was caught and finally purchased by the king's steward. Tom was brought before the king, impaled on a fork, but the affairs of state were not to be interrupted then by such a slender cause and so the cook was instructed to keep Tom a prisoner, which he did by binding him hand and foot and placing him in a mouse trap. After an interval of a week, Tom was taken before the king, but he made such a good plea that he was pardoned and taken into favor.

FIG. 10. THE THISTLE-EATING COW WHICH SWALLOWED TOM.

FIG. 11. KING ARTHUR RECEIVING A REPORT, ABOUT TOM, FROM THE DOCTOR (1630 ED.).

His troubles, however, were not at an end. While riding on a mouse, a-hunting with the king, a farmer's cat captured both and ran to the top of a tree. After a sad and bloody fight during which the cat scratched and Tom ran his sword through her, the cat dropped him. From this encounter he did not recover. His injuries were too severe. And so the fairy queen sent "a mighty swarm of pretty Fairy Sprites" for him.

> They put him in a winding sheet,
> More white than Lillies fair,
> These Fairies all with music sweet
> Did mount the lofty air.

But "death's fatal arrows prov'd in vain," because "he was hurried back again down from the Fairy Land," and a third part of the tale deals with "his Marvellous Acts of Manhood, performed after his second return from Fairy Land." His first adventure, however, after reaching the earth was so undignified and so devoid of romanticism that only in a "limited and unexpurgated" edition would it be proper to mention it. In due course Tom finally appeared before King Thunston's court where he underwent another trial, coming through, as usual, with honors and ingratiating himself with the king. In

FIG. 12. FRONTISPIECE TO KANE O'HARA'S BURLETTA "TOM THUMB" SHOWING GEORGE CRUIKSHANK'S CONCEPTION OF TOM. (1830).

fact the king thought so highly of Tom that he bought him a coach drawn by six mice and he lived in splendid ease. But horrors! the microscopic wretch attempted to ravish the queen and,

The Queen, with rage and fury fir'd,
To see herself abus'd,
That of the King she then desir'd,
Tom Thumb might be accus'd.

That nothing would her wrath appease,
To free her from all strife,
Or set her mind at perfect ease,
Until she had his life.

Tom escaped this time on a butterfly which after giving him an uncomfortable ride, unluckily flew back to the court where Tom was discovered and captured. He was brought to trial, a very sick man, and

So the King his sentence he declar'd,
How hanged he should be,
And that a Gibbet should be rear'd,
And none should set him free.

Tom was imprisoned in a mousetrap, but a cat, mistaking him for a mouse, broke his prison and in endeavoring to escape he fell into a spider's web.

The spider, watching for his Prey,
Tom took to be a fly,
And seized him without delay,
Regarding not his cry.

The blood out of his body drains,
He yielded up his breath;
Thus he was freed from all Pains
By his unlook'd for death.

Thus you have heard his actions all,
Likewise his actions great,
His Rise, his Progress, and his fall,
Thus ushered in by fate.

Although he's dead, his Memory lives,
Recorded ever sure;
His very name some pleasure gives,
And ever will endure.

This in brief is the story of Tom Thumb as told in three parts. During the reigns of James I, Charles I and

Charles II, Tom Thumb enjoyed continued popularity, and he was frequently mentioned by contemporary authors. Ritson in 1791, when he reprinted the 1630 version of Tom Thumb in his "Pieces of Ancient Popular Poetry" (London), said that "every city, town, village, shop, stall, man, woman and child in the kingdom" was familiar with it. John Newbery published editions in 1768, 1786 and 1789. Various versions circulated as chapbooks down to the beginning of the nineteenth century and even later. The tale was popular in this country, too. In the Boston, Massachusetts, *Chronicle* for August 29, 1768, John Mein adver-

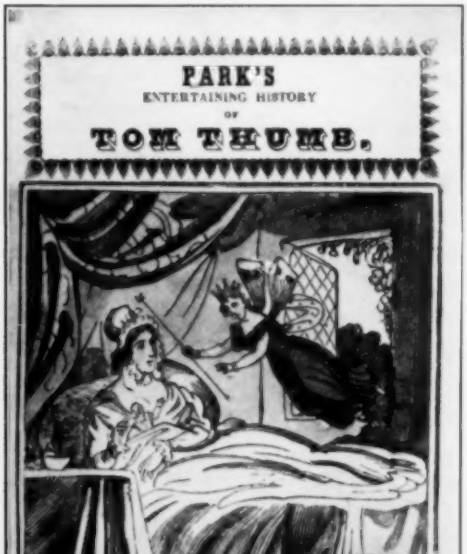

PARK'S
ENTERTAINING HISTORY
OF
TOM THUMB.
In good King A- hur's reign, Tom's history first begun,
A farmer's wife had sigh'd in vain to have a darling son!
A fairy listen'd to her call, and granted her the same,
But being very small, Tom Thumb she did him name.
LONDON:
Printed and Published by A. Park 47, Leonard Street,

FIG. 13. TITLE PAGE OF PARK'S "TOM THUMB."

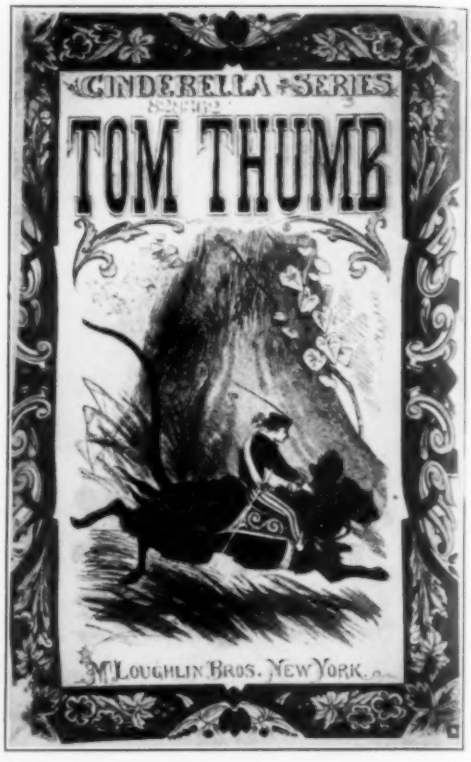
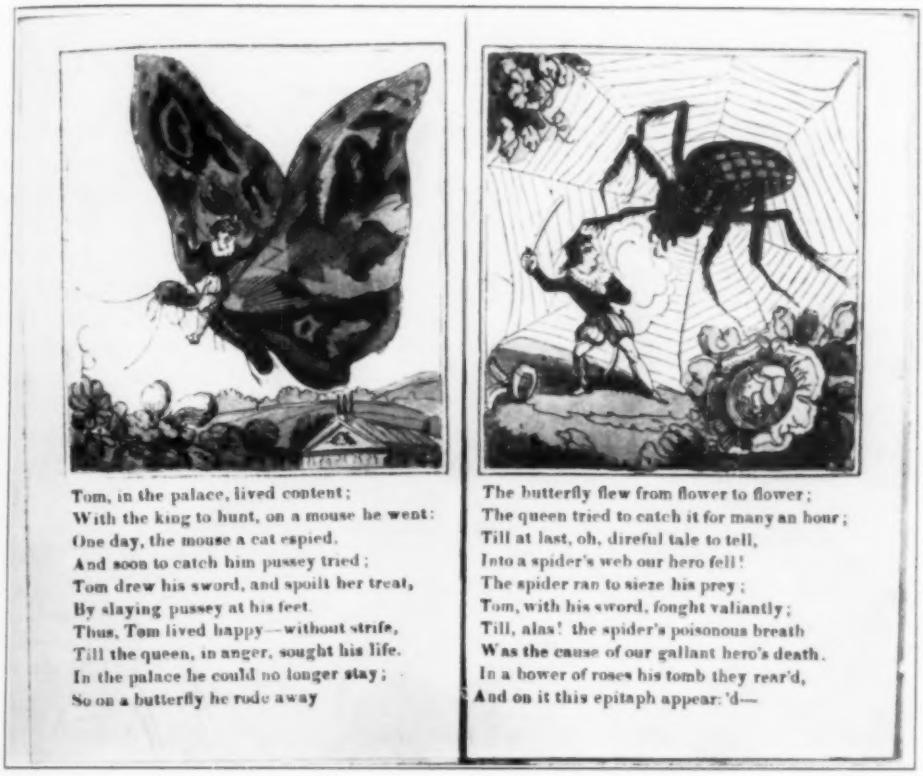


FIG. 14. TITLE PAGE OF McLOUGHLIN BROTHERS' TOM THUMB (1870 OR 1871).

tised "The Famous Tommy Thumb's Little Story Book: Containing His Life and Surprising Adventures," etc. "London: Printed for S. Crowder." And in 1686, or some 80 years earlier, John Dunton sold "The History of Tom Thumb" in his Boston warehouse. Although these titles were imported, the tale was printed in this country. John Boyle, of Boston, in 1771 printed "The Famous Tommy Thumb's Little Story-Book. Containing his Life and Adventures." And later, in 1813, N. Coverly, Jr., Milk Street, Boston, printed "The Life and Death of Tom Thumb." However, English editions with their quaint woodcut illustrations continued to circulate in this country until the middle of the nineteenth century, some gaily colored in red, pink and green. Mc-



Tom, in the palace, lived content;
With the king to hunt, on a mouse he went:
One day, the mouse a cat espied,
And soon to catch him pussey tried;
Tom drew his sword, and spoilt her treat,
By slaying pussey at his feet.
Thus, Tom lived happy—without strife,
Till the queen, in anger, sought his life.
In the palace he could no longer stay;
So on a butterfly he rode away

The butterfly flew from flower to flower;
The queen tried to catch it for many an hour;
Till at last, oh, direful tale to tell,
Into a spider's web our hero fell!
The spider ran to sieze his prey;
Tom, with his sword, fought valiantly;
Till, alas! the spider's poisonous breath
Was the cause of our gallant hero's death.
In a bower of roses his tomb they rear'd,
And on it this epitaph appear: 'd—

FIG. 15. TWO PAGES FROM PARK'S HISTORY OF TOM THUMB. (184–).

Loughlin Brothers in 1870 or 1871 published "Tom Thumb" in their "Cinderella Series" and at present various American publishers of children's books usually include a stray title of "Tom Thumb" in their lists. But all in all, Tom is not nearly so popular now as he was fifty or seventy-five years ago.

Ever since the story has been current, Tom's thrilling adventures have been told and retold, with modifications by each generation, and many variations occur in the numerous editions within a generation. Although the coarseness of the seventeenth century would not be permitted to circulate in the nurseries of to-day, it should be remembered that in the seventeenth century Tom Thumb was as popular with adults as with children, and no doubt some of the allusions in the early accounts were not intended particularly for childish understanding.

Some of the liberties taken with the text appear to be quite unnecessary. In present-day versions, no one will object to the deletion of expressions which are now highly unconventional and which are objectionable to those of squeamish sensibilities—at least not so long as the early versions are obtainable. However, nearly every one who has arranged the tale for publication has made changes, probably under the delusion that the original was being improved upon. And so in some present-day accounts we are told that Merlin, because the plowman's wife refused him admittance to her home, when he was cold, revenged himself by seeing to it that her baby boy

grew no bigger than her thumb. The thistle which the cow ate in 1630 has now become a buttercup. Tom's hat is made, not of an oak leaf but of a rose leaf. And under no circumstances is Tom now allowed to get beyond the cow's mouth. His mother either saves him in time or the cow sneezes him to safety or the cow, hearing strange noises in her throat, simply opens her mouth without further ado and Tom falls out.

The real reason for the queen's displeasure with Tom is never even hinted at. That of course would be unthinkable, and so the queen is made to appear jealous because Tom gets a coach and six mice, or no reason is given at all. Kisses have been injected into modern versions also. Tom's mother kisses him after he escapes from the pudding and before she puts him to bed. Such an act of endearment seems strangely out of place in Tom Thumb's life. He is not at all kissable, and his adventures are not of the sort that admit expressions of affection. But when "adapters" and "arrangers" go so far as to have Tom place carpet tacks in the path of the cat—then something should be done about it.

Many years ago, Dr. Wagstaffe concluded that although Tom Thumb was looked upon merely as entertainment for children, it was "perhaps a performance not unworthy the perusal of the judicious." Dr. Wagstaffe believed that the design of the tale was to recommend virtue and to demonstrate that "however any one may labour under the disadvantages of stature and deformity, or the meanness of parentage, yet if his mind and actions are above the ordinary level, those very disadvantages that seem to depress him add a lustre to his character." Even now some of our "adapters" show a trace of Hannah More-ism at the ends of their adaptations, but for the most part Tom Thumb has been fortunate in escaping the clutches of the moralists.

According to tradition, Tom Thumb died at Lincoln, which was one of the five Danish towns of England, and according to the same tradition his tombstone was a little blue flagstone, in the cathedral, which has long since disappeared. Although the authenticity of this remains uncertain, there can be no doubt about Tom Thumb himself being very much alive to-day, which is my excuse for bringing him up, as Thomas Nashe has said, "thicke and threefold, when better things lie dead."

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

HEREDITY AND DISEASE

By Dr. CHARLES B. DAVENPORT

DIRECTOR, STATION FOR EXPERIMENTAL EVOLUTION, CARNEGIE INSTITUTION OF WASHINGTON, COLD SPRING HARBOR, L. I., N. Y.

SOME years ago, in speaking with a medical man about the possible hereditary factor in tuberculosis, he showed astonishment that I should suggest there might be such a factor. He stated that it is now well known that the *Bacillus tuberculosis* is the sole cause of tuberculosis in man. The obvious response was to call his attention to the fact that the *Bacillus tuberculosis* can be inoculated into a horse or goat without producing symptoms of tuberculosis and, while practically every adult person carries *Bacillus tuberculosis* in his body, only a small fraction of persons have what the medical men would call tuberculosis. The symptoms that we call tuberculosis are the reaction of particularly susceptible individuals, belonging to hereditarily non-resistant strains, to the presence and growth in their bodies of *Bacillus tuberculosis*. The constitutional, hereditary, genetical factor is as important in producing the disease as the parasitic bacillus.

Formerly we heard much of the diathesis, or constitution, that is favorable to the development of a particular disease. With the demonstration of the importance of the germ theory of disease many medical men have forgotten the importance of constitution. To-day, the pendulum is swinging back, largely on account of modern genetical studies. First of all, it has been clearly shown by Alexander Graham Bell and others that there is inheritance of longevity. If both your parents have lived to be over 80 years of age you will probably live to be over 53; while if both parents died under 60 years the average age of the children is only 33. Now in a world full of hazards of infections, longevity can only mean great bodily resistance to germs that incite diseases.

Heredity is exceedingly important in the resistance of plants to disease, as has been shown experimentally. Thus, some years ago the sugar industry was menaced by the mosaic disease, which in some years wiped out whole plantations of sugar cane. An East Indian Java cane has proved to be highly resistant to this disease and has saved the industry. The germs of mosaic have not been eliminated, but genetic immunity has been bred into the sugar cane. Many similar cases are known to plant breeders.

Similarly, experimentalists have found in different families of guinea-pigs a marked difference in resistance to tuberculosis. In humans a high correlation in the incidence of tuberculosis has been found between parents and offspring, but only a slight one between husband and wife, who are not blood relatives.

Cancer is a very wide-spread disease. Yet not every one can die of cancer. This has been shown experimentally in breeding mice. Some of the cancer tissue from a dying mouse inoculated into her sisters may cause them all to die of cancer, but similar cancer tissue inoculated into another family of mice will be destroyed in their bodies and cause no tumor at all.

Still another disease that illustrates the relation of constitution to symptoms is goiter. This is commonly thought to be due to insufficiency of iodine in the water or food. There are regions where

the enlarged thyroid gland is very common, or endemic, not only among people but among dogs and other domestic animals. However, even in such regions only a fraction of the population is affected; but in certain families 100 per cent. are. There are family differences in immunity.

But how then do we account for the fact that endemic goiter occurs only where there is little iodine in the water? The explanation seems to be this. Humans differ in the effectiveness of the thyroid gland, and the degree of effectiveness is hereditary. Supposing the population placed like the successive strata of a cliff, with the least resistant at the bottom and the most resistant at the top. Let us imagine a tide of noxious environment (especially absence of iodine) to be rising with increasing noxiousness up this cliff. A low wave of noxiousness will affect only those with imperfectly functioning thyroid glands, and, therefore, only a small part of the population will be affected, but if the tide of increasing noxiousness rises it will involve a larger proportion of the population, taking in even those with fairly effective thyroid glands.

Note the delicate relation between constitution and environment upon which the disease, goiter, depends. The pathological result depends upon a disharmonious relation between heredity and environment—a thyroid too insufficient to function with the insufficient iodine intake. For a constitutionally effective thyroid a small iodine intake would suffice. Even a poorly efficient thyroid might get along without enlarging were there much iodine in the water.

This example of goiter shows clearly the relation between constitution and medication. Goiter results from a disharmony. Goiter is frequently successfully treated by iodized salt. Disharmony may be corrected by artificial means—by medicine. This principle would seem to be of general application. The girl who is going into a decline with tuberculosis may be saved by open air, good food, cod-liver oil and other care. For many, the excellent conditions in a sanitarium obliterate the disharmony between poor constitution and medium environment. If, however, the constitution is inherently very unresistant, even the excellent environment may fail. On the other hand, many highly resistant families can live under the hard conditions imposed by crowding, poor air and insufficient food without showing tuberculosis. In general, persons with strong constitution can withstand sub-optimal conditions, but where the constitution is weak the conditions of life must be the best possible.

These considerations should bring hope to the constitutionally weak and point a moral to those who wish their children to be constitutionally strong, resistant, effective in a world where the conditions can not always be the best. The hope lies in this, that if a person with a constitutional weakness early learns of that weakness and persistently keeps himself in an optimal environment he may live long. It is a function of sanitation to provide this optimal environment. It is the function of medicine to restore the harmonious balance between constitution and environment, once it is threatened. Often in the absence of knowledge concerning the constitution of the individual the medical profession advises a blanket protection. Thus we give smallpox vaccine to all. In the army all received typhoid anti-toxin. We make no allowance for natural resistance or immunity because it is impracticable to determine it.

Finally, where in the scheme of health does heredity come in? Constitution is the great fact that we must recognize. Most of us have a constitution that is sufficient for most purposes and which will last for seven or more decades. For those with some constitutional limitation it is necessary to know, first, what that limitation is and to adapt one's life—including one's biochemical life—to it. Every parent should know these consti-

tutional limitatians of his children; how to protect the child from disharmony between constitution and environment and how to restore any threatened disharmony. A knowledge of heredity of the patient is necessary to the best results by the physician. A knowledge of one's own heredity is necessary for the more effective conduct of life. Know thyself; especially know thy constitution and its limitations!

And how shall we know our constitution? The first step is obviously to know our families and to learn how the constitutional factors have revealed themselves in our nearest kin. The study of the family history may reveal great causes of satisfaction. In my immediate family I find no insanity, no hemophilia or bleeding, no case of brittle bone. Indeed there are 100 or more diseases or defects that I have never heard of in my family. Glory be! But there is tuberculosis, arteriosclerosis. Very well. I must take particular pains to avoid the environment that permits these diseases to thrive. In general, I would urge that as much individual attention be given to the consideration of one's constitution—one's heredity—as to the treatment of disease.

Finally in marriage-mating careful consideration should be given to constitution. Of course one will hardly marry a physical or mental wreck, but one should go farther than that. It is undesirable for the deaf to marry the deaf; for two myopics or two over-active persons to marry each other. If you have any constitutional limitation select a mate from a family that does not show the same leading limitation and so shall the children receive a stronger heritage. There is a limitation to the aid that medicine can afford the weak constitution. The need is indeed greater now than ever, in these days of small families, of considering while selecting a mate the probable consequences to the children. This is the reason for eugenics.

IDENTICAL TWINS

By Professor H. H. NEWMAN

DEPARTMENT OF ZOOLOGY, UNIVERSITY OF CHICAGO

IDENTICAL twins are those twins that look so much alike that they are often mistaken for each other. When they are babies one sometimes gets two baths and the other none, and when they are grown up even their best friends call one by the name of the other. About one fourth of all twins are identical twins, and since about one birth out of every 88 is a twin birth, one birth in every 352 is an identical twin birth.

Identical twins are of peculiar scientific interest, for they are the product of the symmetrical division of a single embryo, derived from a single fertilized egg. Such a fertilized egg typically develops into a single individual with a body composed of two nearly symmetrical halves. One half is not strictly the duplicate of the other but the reversed, or mirror-image duplicate of it. Thus your two hands are not really duplicates, but your right hand is like the image of your left seen in a mirror. Now a pair of identical twins starts out to become an ordinary single individual, with right and left symmetrical halves, but some delay or some hitch in the developmental process causes the right and left half embryos to separate, and each half to grow into a whole individual. Frequently the derivation of the twins from right and left halves of the embryo body is reflected in the fact that one of the twins is a right-hander, the other a left-hander; one of them has the whorl in the crown of the hair twisted to the left, the other to the right.

An interesting study has been made of the degree of resemblance existing be-

tween identical twins. They are always both of the same sex in a pair, and therefore identical in this respect. They have the same or nearly the same eye color, hair color, skin color; nearly the same irregularities in their teeth, nearly the same finger-prints, nearly the same shapes of ears, nearly the same features, body build, etc. In other words, they are almost complete duplicates in all their hereditary characteristics. But why are they not exact duplicates? For the same reason that the two sides of the body of a single individual are never exactly alike. Compare your two hands, your two feet, your two ears, your teeth on the opposite sides of your dental arches. They nearly always show minor differences.

Now it is very significant that when accurate measurements are made first between equivalent parts of the two sides of single individuals and then of the characters of pairs of twins, the two sides of the body are about 90 per cent. identical, and so are identical twins. Identical twins then are not strictly identical but only just as identical as the two sides of single individuals.

The two sides of the body of a person are, of course, identical in their heredity. No one doubts that for a minute, but perhaps you have not made the next inevitable step in reasoning from the facts. This next step is that the two individuals of a pair of identical twins have identical heredities. Each has inherited exactly the same combination of maternal and paternal characters from the two parents.

It is this fact that makes identical twins so important for scientific work, and for the following reason: There is an old problem that badly needs solution, namely, which is more important in the development of an individual, differences in heredity or differences in the environment—the old problem of nature or nurture. When the heredity of every individual is different and the environment also differs, how can we determine which of these differences have been more effective? It can't be done. But if we could find two individuals with exactly the same heredity and rear them under different environments we could conclude that the extent to which they remain similar is a measure of their heredity and the extent to which they become different under different environments is a measure of the effectiveness of the environment in producing differences.

It is just in this connection that identical twins come to our aid, for they represent for each pair two individuals with identical heredity. If we could separate pairs of identical twins in infancy and rear one in poverty and the other in wealth, one in the city and the other in the country, one in the tropics and the other in the Arctic regions, educate one and leave the other uneducated, we could determine just what are the effects on the individuals of such differences in environment. Of course, we can not cold-bloodedly separate infant twins and subject them to environmental extremes, but many equivalent experiments have been accidentally performed for us, and all we have to do is to determine the results. I mean to say that once in a while a pair of identical twins are left as orphans and are adopted one by one family and the other by another family. Such families may live in very different environments and the twins of a pair may be placed under very different living conditions, involving different s o c i a l levels, different educational careers, and different sanitary or health conditions. These separated twins may also have very different experiences. When we discover such a pair of identical twins separated in infancy and reared apart, we realize that we have a rare and valuable experiment already performed for us that needs only careful study to give us valuable information about heredity and environment.

So far we have studied six cases of identical twins reared apart, and these

have been compared with regard to their physical, mental and temperamental characters, and checked against the base line of the average differences of 50 pairs of identical twins reared together. The results so far indicate that the environment very distinctly modifies some physical characters such as weight, general health, etc., but does not alter others such as eye-color, hair color, teeth, features, etc. Moreover, the environment profoundly modifies those characters described by the terms "intelligence" and "personality." In some cases the intelligence of a pair of separated twins was three times as different as the average of 50 pairs of twins reared together. But after full credit is given to the modifying effect of the environment, the fact stands out sharply that hereditary resemblances remain most strikingly close. The six cases already studied of identical twins reared apart showed the following facts:—

Case I. A pair of twin young women, one with very much more formal education than the other, but with a much more varied social experience, showed after twenty-odd years of separation the following condition: They were practically identical physically and in intelligence, but were extremely different in temperament—in personality.

Case II. A pair of twin young women, one reared in London, England, and the other in a small Ontario town. They had about the same amount and kind of education. When tested, the colonial girl was very much more intelligent and in much better physical condition. In temperament—personality, they were extremely similar.

Case III. Two twin young women separated over 20 years, reared in about the same social and physical conditions, but one had far more education than the other. Physically and temperamentally they were extraordinarily similar, but the more educated twin was strikingly more intelligent.

Case IV. Two twin young men separated over 20 years, one reared in cities of some size, the other reared in country villages, both with high school education. The city boy was in much better physical condition and was slightly more intelligent. In temperament—personality—they were as utterly different as two persons chosen at random.

Case V. Two twin girls, separated for 28 years, but visiting each other from time to time. One has always lived on a farm, the other has lived in a small town and has spent most of her time indoors. The farm girl stopped school after the grades, the town girl went through high school and has studied music for 20 years. These girls differ equally strongly in all three respects: physically, intellectually and temperamentally. They show the most pronounced effects of environmental differences of any of the pairs studied.

Case VI. Twin girls, separated for 37 years, both married and with four and six children, respectively. One married a man who has always made a good deal of money, the other married a poor man. The life of one has been easy, that of the other very hard. Both nearly completed high school. There is very little difference between them in I. Q., only minor differences in temperament, but a very striking difference in physical condition. The twin who has had an easy life seems hardly over thirty while the one who has had a hard life seems eight or ten years older.

I earnestly wish we could find and study about four more cases such as these. If we had ten cases and they were as consistent as those already studied, we might be able to arrive at some very definite conclusions as to the relative effects of heredity and environment in producing human differences.

A great service would be rendered to science by any one who could give information about identical twins reared apart. If you know of any such cases please notify this station or write directly to Professor H. H. Newman, University of Chicago.

UNTANGLING ONE OF NATURE'S PUZZLES

By Professor B. SMITH HOPKINS

DEPARTMENT OF CHEMISTRY, UNIVERSITY OF ILLINOIS

MUCH of the chemist's work is concerned with the problem of the preparation of materials of known purity. Most of our naturally occurring raw materials are more or less complicated mixtures of substances whose properties are similar. If from these mixtures pure chemical materials are required, the work of purification frequently becomes the chief task in meeting the demands of modern civilization. For example, common salt, one of our most extensively used chemical materials, is found widely distributed in the earth's crust both in the form of brine and as crystalline rock salt. It is, however, rarely found free from admixture with other materials, such as rock, soil and especially other soluble compounds whose influence upon the salt is marked. Some of these compounds, like the bromides, give the salt a bitter taste, while others, like sodium sulfate, absorb moisture from the atmosphere and make the salt sticky or cause it to form a hard cake. For most purposes the removal of such impurities from the salt is demanded for very obvious reasons. Our modern standards are becoming more and more insistent that salt must be "all salt," and as a consequence the manufacturing chemist must continually improve his methods of purification. The rock and soil are easily removed by taking advantage of the fact that salt dissolves in water; consequently the simple process of filtering removes these impurities almost completely. Such treatment, however, will have very little influence upon the task of removing the soluble compounds.

In the purification of salt two general methods are available: (1) addition to the brine of some chemical substance which will change the soluble impurity to an insoluble form, thus permitting its removal by filtration; and (2) the evaporation of the brine under carefully determined conditions such that crystals of pure salt may be obtained while the undesirable impurities are separated. It is obvious that both of these steps must be taken with care, if they are to be successful. No material can be added to the brine to remove an impurity if the added substance will itself be objectionable. Moreover, the amount of the compound added in this way must be definitely determined in order that an excess may be avoided. In the purification by crystallization it must be remembered that under some circumstances the impurities will crystallize before or along with the salt. Consequently, the conditions must be controlled in such a way that the salt crystals may be separated as completely as possible from those substances whose removal is desired. One crystallization will never completely separate two soluble compounds, because the crystals which form first will always be wet with the solution of the other compound. Thorough washing of the crystals will aid materially in meeting this difficulty, and several repetitions of the crystallization process are effective in bringing about a reasonably complete separation. It is very obvious, however, that the preparation of chemically pure sodium chloride from such complicated mixtures of salts as are found in seawater is a task which presents difficulties of considerable proportions.

This simple illustration will serve to indicate the difficulties encountered in the chemist's perennial task of preparing a chemically pure substance from a naturally occurring raw material. It is true that nature in rare cases supplies us with material in a high state of purity. A clear water-white diamond represents

one of the purest forms of carbon which is known, and crystals of clear quartz are pure silica, but these are exceptional forms of matter. Their adaptation to commercial uses requires such processes as cutting, polishing and grinding, with which the chemist is not concerned, since they are purely mechanical. At the opposite extreme we find many useful substances required in a high state of purity which are won from natural sources of a most unpromising character. During 1929 the world produced over two million tons of copper, most of which had a purity of at least 99.9 per cent. Some of this useful metal was obtained from ore which contained as little as one per cent. of copper. The world's production of gold in 1929 exceeded 400 million dollars in value, and part of this was obtained from ore which yielded as little as 1/20 oz. per ton of ore. It is also claimed that radium has been successfully won from ore so poor that one ounce of radium would require the concentration of all this precious metal that was contained in 10,000 tons of ore.

The production of high-grade copper for electric wiring from a low-grade ore represents a problem in intensive purification on a large scale. The concentration of high purity gold or of radium from their ordinary sources illustrates an extreme case of purification, in which the dross is truly enormous. Nature furnishes many puzzles in which we are challenged to separate a useful material from an almost overwhelming proportion of waste. Many of these problems have already been solved so successfully that the results command our respect and excite our admiration. But Mother Nature has given us many puzzles which have not yet been solved; these we are apt to regard with awe and dread, but if the object to be obtained is a desirable one they should challenge our intelligence and inspire an intensive effort for their solution.

One of the most puzzling problems in purification, certainly in the field of inorganic chemistry, is furnished by the group of elements commonly known as the rare earth group. This group may conveniently be thought of as a collection of at least 15 elements which through some fantasy of nature have been crowded into a space which is usually occupied by a single element. All the known elements are arranged in an orderly fashion in the systematic tabulation known as the Periodic Table. Throughout this table each element is given a single space; in a few cases three elements occupy one space and in the single instance of the rare earth group do we have more than three elements crowded together into one space. These 15 elements of the rare earth group are almost invariably all found together in the same minerals, and in addition there are two others which generally accompany them. To add to the complexity of this puzzle there are, in addition to the 17 elements which are generally thought of as comprising the rare earth group, at least a dozen closely related elements which are frequently present in rare earth ores. At least three or four of these closely related elements must always be expected in every rare earth ore, and it is not uncommon to find most of them present in a single ore.

Thus it appears that the rare earth group presents to the inorganic chemist a puzzle which is complicated in the extreme by the fact that the ores in which this group occurs contain from 15 to 20 or more elements. The untangling of so complicated a puzzle as this is in itself no simple task. But when attempts are made to solve this riddle other serious obstacles are immediately encountered. While some rare earth ores are available in large quantity at a reasonable cost, most of the minerals containing these compounds are scarce and difficult to obtain. As a consequence the initial cost of the raw material is generally high and the amount available at any price

is definitely limited. When an adequate supply of ore is obtained difficulties are encountered because the minerals are refractory and yield reluctantly to chemical treatment. After the material is brought into solution and attempts are made to untangle the resulting complex mixture of salts by resolving it into a series of definite individual chemical compounds, new and perplexing obstacles are encountered. When an attempt is made to apply the methods of separation which are usually employed in the purification of a chemical mixture, extremely slow progress is made for the reason that the elements of this group are very closely related chemically. Any reagent which affects one will generally react with them all and to about the same degree. As a result special methods must be applied and the best of these are lamentably lacking in efficiency. As a consequence the most useful methods of purification which are now known are frightfully wasteful and wholly unsatisfactory.

Thus it appears that the process of untangling this complicated puzzle which nature has given us is difficult and expensive alike from the standpoint of time, money and patience. Some members of the rare earth group have been prepared in considerable quantity and in a high state of purity; these may now be purchased in the open market in large bulk and at a reasonable cost. Most of the individual members of the group have been prepared in a satisfactory state of purity, as a result of long, painstaking and patient effort. But some separations have never been accomplished completely, because several portions of the puzzle remain yet to be solved. For this reason the compounds of some of the rarer members of the group are almost or quite unattainable. With this situation in mind it is easy to understand why illinium, which appears to be the rarest member of the group, if not one of the rarest elements now known, escaped detection for so many years.

The method commonly employed in the separation of the members of this group are based upon one of two facts: (1) There is a gradual, though slight, change in the solubility of the salts of these metals and (2) there is a gradual decrease in the chemical activity of the metals as we proceed in regular order from the first to the last member of the group. According to the first fact, if we have a saturated solution of the bromates of the whole group and evaporate a part of the solvent it is obvious that some of the salts must crystallize out. If these crystals are examined and their composition compared with that of the mother liquor it is found that the crystals are richer in those members which are more difficultly soluble, while the solution contains a larger proportion of the more readily soluble compounds. If the process of partial crystallization is repeated with both the crystals and the solution, there will be still greater separations of the more difficultly soluble salts from those which are more readily kept in solution.

By repeating this process of fractional crystallization many hundreds of times, the original mixture of salts may be divided into a series of fractions, each one of which differs somewhat in composition from that of its neighbors. It is obvious, however, that complete separations of chemical individuals can not be expected by this method, since the differences in solubility are gradual and small. As a result fractional crytallization alone is rarely if ever depended upon to secure a chemically pure compound. The method works best for any salt which is either the most difficultly soluble or the most readily soluble of the series. Usually methods of fractional crystallization are employed as a means of splitting a large volume of a highly complex solution into a series of fractions, each of which is composed mainly

of one or two individual compounds, with a small admixture of one or two of the most closely related compounds. In other words fractional crystallization is the first step in untangling the highly complex rare earth group.

Methods depending on the varying degree of chemical activity are of various types. If a precipitant like ammonia is added in excess to a mixed rare earth solution all the rare earth material would be precipitated. But if a very small amount of the precipitant is added only the weaker metals would be thrown out of solution. Similarly, if the mixed rare earth nitrates are heated, insoluble compounds are formed; but if the heating is carefully controlled only the weaker metals will be changed to the insoluble form. These and other similar methods are used to fractionate the relatively simple mixtures obtained by fractional crystallization. In general, a carefully manipulated combination of fractional crystallization and fractional precipitation or thermal decomposition will give the most satisfactory results yet obtained in the effort to untangle this rare earth puzzle.

Many other attempts have been made to find more satisfactory methods of separating the members of this group. In general they have not been as satisfactory as those which have been in use many years. New ideas are continually being developed and new methods of attack are being used. Progress is being made in the attempts to learn more about this intricate group. Probably the most valuable new method which has recently been used is that of electrolytic reduction, for which we are indebted to Professor L. F. Yntema. By this means he has prepared highly purified europium and ytterbium, two of the most rare and most difficultly separated members of the entire group.

Why should any one be interested in untangling so complicating a puzzle? What is to be gained from such work as this? Of what possible use is it all? Such questions as these force themselves upon us when we realize that a lifetime of hard work may be expended with apparently little actual progress. There are many reasons why the scientist persists in his efforts even in the presence of discouragement and disappointment. No one can predict in advance the value of any scientific investigation. Some of the world's greatest achievements have come from the most unexpected sources. Any effort which extends the boundaries of our intellectual horizon is worth while. To the worker in the field of the rare earths there is also the conviction that perhaps this group holds the key by which we may be able to unlock the storehouse of information of the whole periodic system.

If we can learn to understand the relationship of these elements to each other and to the more important commercial metals, it may be possible to use this information for a better understanding of those elements which we now consider commercially important. It is only by patient, persistent and devoted effort of this sort that scientific progress may be made. In addition the rare earth worker is stimulated by the conviction that the rare earth elements must have been put here for some specific use. It is only our own ignorance concerning them that makes them appear useless. Perhaps some one of them may prove to be extremely useful, as, for example, as a specific remedy for a baffling malignant disease. Surely no greater contribution to modern life could be desired than one which contributes definitely to the comfort, happiness, security and welfare of the human race.

CHEMICAL RESEARCH IN ICE MANUFACTURE

By Professor D. B. KEYES

HEAD OF THE CHEMICAL ENGINEERING DIVISION, ENGINEERING EXPERIMENT STATION, UNIVERSITY OF ILLINOIS

In considering the industrial growth of the country during the past twenty years it is interesting to discover that one of the major industries which developed during this period was the production of artificial ice. It is only possible to gain an accurate conception of the true proportions of this development by considering the fact that, during 1929, 54,000,000 tons of ice were produced, the retail value of which was approximately $400,000,000. Since, in addition to its size, the industry is intimately connected with the efficient maintenance of public health, its problems deserve particular attention in the form of effective research. In the past this attention has been centered in studies concerned with the efficient operation of the mechanical units comprising the refrigerating cycle. During a recent investigation conducted at the University of Illinois, however, problems more intimately concerned in the production of artificial ice itself have been made the basis of extensive research.

From a purely mechanical standpoint the manufacturing process itself does not involve an extremely involved procedure. A gaseous refrigerant, usually ammonia, is compressed to a liquid by means of mechanically operated compressors and is then allowed to boil at the expense of heat absorbed from a concentrated salt solution containing either sodium or calcium chloride, commonly called a brine, the freezing point of which is below that of pure water. Heat exchange is effected in an apparatus which effectively separates the two liquids by means of a metal wall. The ammonia vaporized during the process is again compressed, cooled in a water condenser and returned as a liquid to the evaporator, thus operating as a continuous, closed system. The net effect of using the refrigerant is to remove heat from the brine and to deliver the heat thus extracted to the condenser water used to cool the ammonia gas following its compression.

The brine, cooled by the removal of heat in the ammonia evaporator, is rapidly circulated past steel cans containing the water to be frozen. Ice is formed at the sides and bottom of the cans, thus leaving the unfrozen water confined in a core bounded by the growing walls of ice. When the water is completely frozen the cans are removed from the brine and placed in a thawing tank which is filled with warm water. Here a thin layer of ice is melted from the sides and bottom of the cans, thus allowing the ice to be removed when the cans are sufficiently inclined. The ice removed, the cans are refilled with water and returned to the freezing tank to yield another crop of ice.

The production of ice is thus seen to result from the expenditure of mechanical energy, the total work required being equivalent to that used by the compressors to return to its original liquid state the ammonia vaporized during the extraction of heat from the brine. In the original plants the only economical motive power available was that obtained from coal burned to pro-

[1] This article is based on data previously published in Engineering Experiment Station Bulletin No. 219, "The Treatment of Water for Ice Manufacture," by Professor Dana Burks, Jr., Chemical Engineering Division, University of Illinois. Published by permission of Dean M. S. Ketchum, director of the Engineering Experiment Station, University of Illinois.

duce steam, a procedure which fortunately served a double purpose, since the steam, after being passed through the compressors, was condensed to produce distilled water. When this water was quietly frozen in cans immersed in the freezing brine the ice produced was invariably transparent, due to the almost complete absence of dissolved salts. The effect of this practice was destined, however, to play an important rôle in the future economic development of the industry itself, for the consuming public finally arrived at the point where it definitely demanded the same degree of transparency that it had been early educated to expect.

The full effect of this demand for transparent ice became apparent with the next major development affecting the industry. With general industrial growth it gradually became evident that power could be more economically produced in central power stations as electrical energy than in small individual steam installations. It was determined in the case of the ice industry, for example, that a ton of coal burned in a steam-driven ice plant would produce from four to six tons of ice while the same fuel burned in a central power station would generate sufficient electrical energy to produce from sixteen to eighteen tons when the operation of the plant was electrified. Electrification was determined to afford savings in ice production cost of from $0.40 to $1.00 per ton.

In the electrified ice plant, however, distilled water was no longer available for use in the freezing process. Natural water supplies had to be used in its place. Such supplies are unfortunately characterized by the presence of varying amounts of dissolved salts and when quietly frozen according to the procedure producing highly transparent ice in the distilled water plants result in a product which is completely opaque, as indicated in Fig. 1.

The reason for the production of opaque ice from solutions containing dissolved salts will be readily understood upon reviewing the conditions to which such solutions are subjected on being cooled. As the temperature is lowered a point is finally reached at which solid water or ice forms, and as heat continues to be absorbed from the solution the formation of ice continues. With the separation of water as ice, however, the salts present in the unfrozen solution are continually concentrated. With ice separating from a solution becoming increasingly more concentrated in dissolved salts a point is finally reached at which either of two

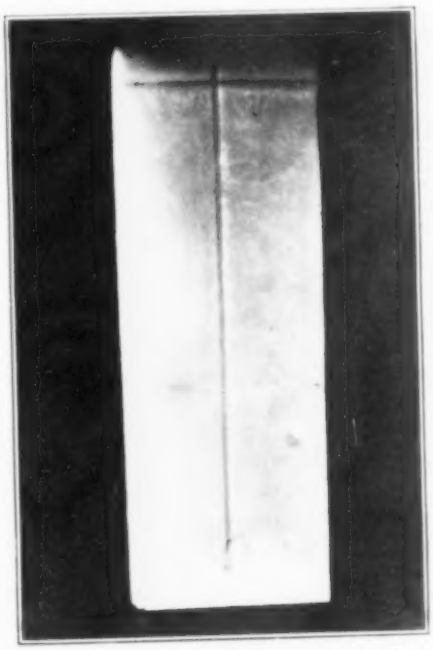


FIG. 1. ICE FROZEN FROM A SOLUTION CONTAINING DISSOLVED SALTS

UNDER CONDITIONS THAT INVARIABLY PRODUCE HIGHLY TRANSPARENT ICE WHEN THE SOLUTION BEING FROZEN IS DISTILLED WATER AND THEREFORE FREE FROM SALTS. THIS ICE IS COMPLETELY OPAQUE, OPACITY HAVING RESULTED FROM THE FACT THAT ITS OPTICAL PROPERTIES HAVE BEEN MATERIALLY AFFECTED BY THE PRESENCE OF THE DISSOLVED SALTS IN THE WATER FROM WHICH THE ICE CRYSTALS FORMED.

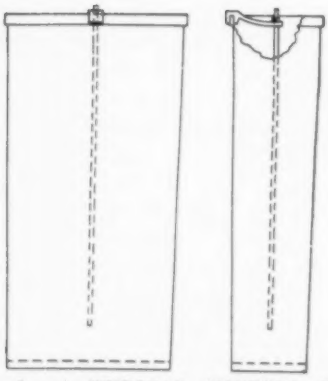


FIG. 2. A TYPICAL METHOD OF APPLYING AIR

TO OBTAIN AGITATION OF THE SOLUTIONS BEING FROZEN ACCORDING TO PROCEDURE WHICH HAS BECOME STANDARDIZED IN THE ICE INDUSTRY. THE AIR ENTERS THE SOLUTION AT A SINGLE POINT, AND MAXIMUM AGITATION RESULTS IN THE CENTER OF THE SOLUTION. WHEN THE INITIAL SALT CONCENTRATION AND THE RATE OF CRYSTALLIZATION ARE HIGH, SUCH AGITATION IS INEFFECTIVE IN PREVENTING THE FORMATION OF OPAQUE ICE AT THE FREEZING SURFACE WHERE THE DISSOLVED SALT HAS A TENDENCY TO CONCENTRATE LOCALLY.

conditions occasioning the formation of opaque ice results.

If the composition of the original solution is such that an insoluble compound may be formed as the result of concentration, solid salt will eventually separate with the ice as an eutectic mixture. Due to the fact that an eutectic generally possesses optical properties which differ from those of pure ice alone the solid will appear opaque. A further disadvantage of the separation of an eutectic mixture lies in the fact that when the ice melts the salt does not redissolve but remains behind as an insoluble sludge, a sludge which either clogs up the drain in the domestic ice box or coats the produce which it is used to cool during shipment to market. The separation of salt with the ice may be effectively prevented, however, by treating the water chemically before it is frozen so that the salts of low solubility are converted into more soluble compounds. This may be effected, for example, by neutralization of the carbonates of calcium and magnesium to the corresponding sulphates, a process commonly accomplished in practice by means of aluminum sulphate.

The second condition occasioning the formation of opaque ice results when the dissolved salts become sufficiently concentrated to affect the physical characteristics of the individual ice crystals themselves. The environment from which a crystal forms exerts a decided effect on both its habit and orientation. When these properties become materially altered, light passing through the solid is sufficiently scattered to cause the mass to appear

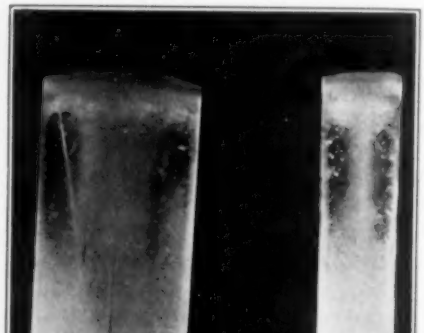


FIG. 3. ICE FROM A SOLUTION CONTAINING A HIGH CONCENTRATION OF DISSOLVED SALTS

FROZEN UNDER CONDITIONS RESULTING FROM AIR AGITATION APPLIED ACCORDING TO THE METHOD ILLUSTRATED IN FIG. 2. THE OPAQUE SHELL ENCASING THE ICE CAKE AND THE THICK OPAQUE CORE ARE TYPICAL RESULTS OF INEFFECTIVE AGITATION. ICE OF THIS QUALITY IS THOROUGHLY UNMARKETABLE. IN THE PAST THE ONLY REMEDY FOR THIS CONDITION HAS BEEN TO DISTIL THE WATER TO REMOVE THE SALTS. SUCH PROCEDURE PREVENTS THE ELECTRIFICATION OF THE MANUFACTURING PROCESS AND MATERIALLY INCREASES THE COST OF PRODUCTION.

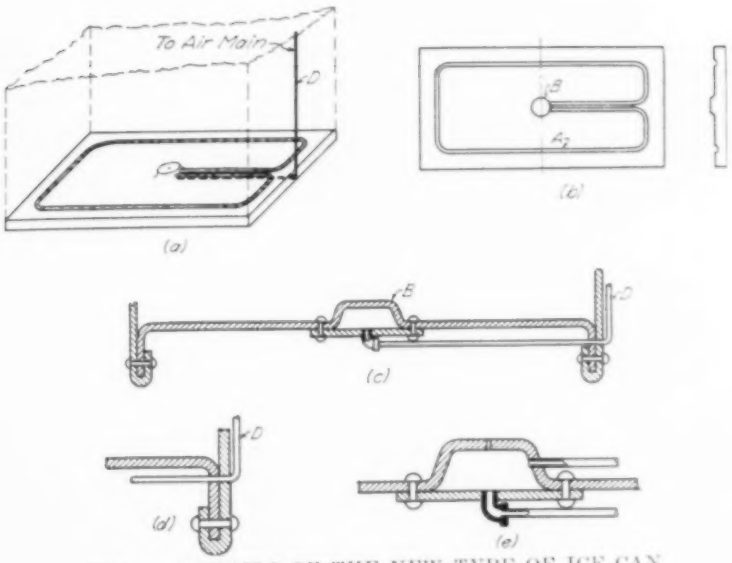


FIG. 4. DETAILS OF THE NEW TYPE OF ICE CAN

DEVELOPED AT THE UNIVERSITY OF ILLINOIS. THE AIR FOR AGITATION IS FORCED TO ENTER THE SOLUTION THROUGH A SERIES OF SMALL HOLES IN A HEADER LOCATED AT THE EXTREME SIDES OF THE CAN AS INDICATED IN (a). THE ICE WHICH INITIALLY FORMS WHILE THE RATE OF CRYSTALLIZATION IS HIGH IS THUS EFFECTIVELY AGITATED. WHEN THE RATE OF CRYSTALLIZATION IS MATERIALLY REDUCED BY THE FORMATION OF A SUFFICIENTLY THICK LAYER OF ICE THROUGH WHICH HEAT MUST BE REMOVED BY THE BRINE, A MUCH SMALLER AMOUNT OF AIR APPLIED FROM A POINT LOCATED CENTRALLY IN THE CAN AT B IN (b) IS SUFFICIENT TO PREVENT THE FORMATION OF OPAQUE ICE. WHEN THE AIR SUPPLY IS REDUCED, ICE FORMING IN FROM THE SIDES OF THE CAN EFFECTIVELY PLUGS THE HOLES IN THE OUTER HEADER AND ALLOWS THE FINAL AIR TO ENTER ONLY FROM THE HOLE AT B. DETAILS OF THE CAN'S CONSTRUCTION ARE INDICATED IN (c), (d) AND (e).

opaque. The general phenomenon is quite common. For example, a large transparent crystal on being pulverized is reduced to a mass which appears opaque, even though the individual crystal units themselves remain perfectly transparent.

To overcome the formation of opacity from this cause, any localized salt concentration at the surface of the growing crystal must be prevented and the unfrozen solution must be removed whenever the salts become concentrated to the point where the orientation and habit of the ice crystals are affected. Removal of the unfrozen core water obviously necessitates refilling the core cavity with a fresh supply of the water originally used.

When the salt solution is first subjected to freezing, extremely rapid cooling takes place at the sides of the metal can. This results from the fact that the heat conductivity of steel is comparatively high, and that the freezing brine in the average plant is maintained at a temperature 16° F. below that at which ice initially forms. The rate at which the first ice makes its appearance must, therefore, be exceedingly high.

This layer of ice which initially forms is, of course, surrounded by all of the unfrozen solution. Actually, however, it may be considered to be bounded by only a thin film of the salt solution. It is, therefore, the conditions existing in this fluid film which not only affect the physical characteristics of the crystal, but also determine the physical characteristics of the final cake of ice. Since growth of the ice surface depends upon its continued ability to remove water

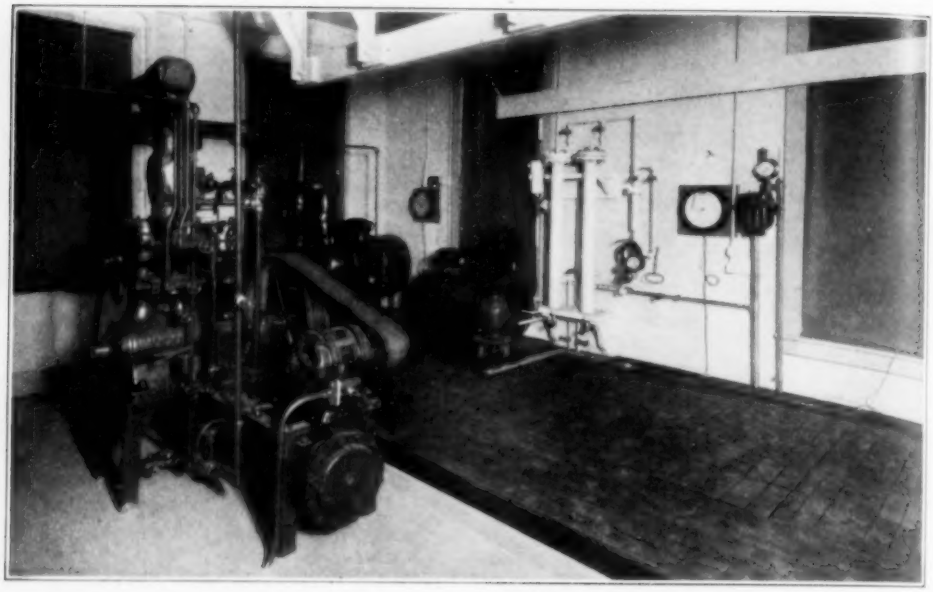


FIG. 5. DETAILS OF THE EXPERIMENTAL ICE PLANT

RECENTLY INSTALLED AT THE UNIVERSITY OF ILLINOIS TO FACILITATE FURTHER INVESTIGATION OF PROBLEMS INVOLVED IN THE EFFICIENT MANUFACTURE OF ARTIFICIAL ICE.

from this fluid film, a decided tendency exists for the salts present in the film to become locally concentrated, the extent of this tendency being dependent upon the initial concentration of the salts in the solution and the rate at which ice is formed at the crystal face. Unless local concentration of the salt is effectively prevented the critical concentration affecting crystal orientation may be reached in the film long before the concentration of the salts in the main body of the unfrozen solution becomes materially altered.

The most effective way to prevent local concentration in the surface film is to agitate the solution as it is being frozen. By agitation the concentrated salt solution formed in the fluid film is mixed with the main body of the solution which is more dilute. In common practice agitation is accomplished by expanding air under pressure into the bottom of the cans filled with water. In rising to the surface the air imparts a certain degree of motion to the liquid which in turn results in the desired mixing. In the past, however, the agitation developed by means of air has been relatively inefficient. The air has been delivered to a single point located near the center of the bottom of the can, as indicated in Fig. 2. As a result the effective movement of the liquid exists in the form of an inverted cone whose apex corresponds to the point of entry of the air. The maximum agitation results not at the sides of the can but in the center. It is at the sides, however, where the most effective agitation is needed and especially is this true during the initial freezing period. An example of inefficient agitation in cases where the initial salt concentration of the water being frozen is high is shown in Fig. 3. As a result of such procedure it has in the past been considered impossible to produce marketable ice from raw water sources containing salts in excess of 600 to 700 parts per million.

During the course of the present investigation a new type of freezing can has been developed whereby the ef-

ficiency of the air agitation imparted to the solution is greatly increased. The construction of the new can is indicated in Fig. 4. The air is forced to enter at the extreme sides of the can, thus causing maximum agitation to always exist at the surface of the ice. In Fig. 6 is shown the result of using the new can in freezing the water which produced, under standard freezing procedure, the thoroughly unmarketable product shown in Fig. 3. For comparison ice frozen from distilled water is shown in Fig. 7.

As a result of the present investigation, it has been determined on the basis of both laboratory and plant scale operations that thoroughly marketable ice can be made from any natural water source which may be considered as an industrial supply. It is, therefore, no longer necessary to distil water in order to render it suitable for use in the production of marketable ice. Approximately one third of the ice produced is still being manufactured in steam plants in the face of the lower operating cost which electrification offers. Undoubtedly factors other than the inability to produce marketable ice in electrified production exist in many steam installations. The steam generating equipment, for example, may have been so recently installed that the depreciation loss incurred by its removal can not yet be economically absorbed. As the result of the present investigation, however, control of the physical and chemical conditions at the surface of the growing ice crystal has been shown to be sufficient to produce clear, transparent ice in electrified plants, whenever desired, from any natural water found in the United States.

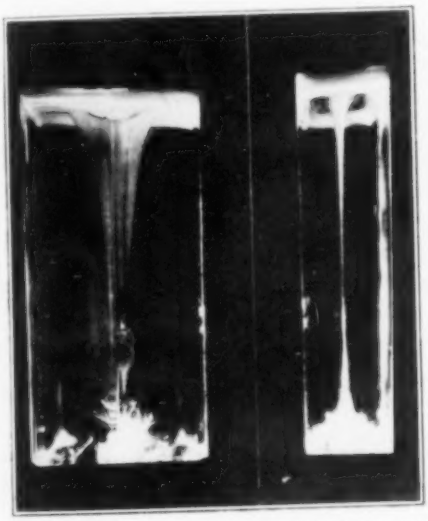


FIG. 6. ICE FROM THE SAME WATER WHICH PRODUCED THE UNMARKETABLE PRODUCT SHOWN IN FIG. 3

FROZEN IN THE NEW TYPE OF ICE CAN SHOWN IN FIG. 4. IN ORDER TO JUDGE THE QUALITY OF THIS ICE FROM THE STANDPOINT OF TRANSPARENCY, REFERENCE SHOULD BE MADE TO FIG. 7, WHICH INDICATES THE ICE PRODUCED FROM DISTILLED WATER AGITATED BY AIR DURING THE FREEZING OPERATION.

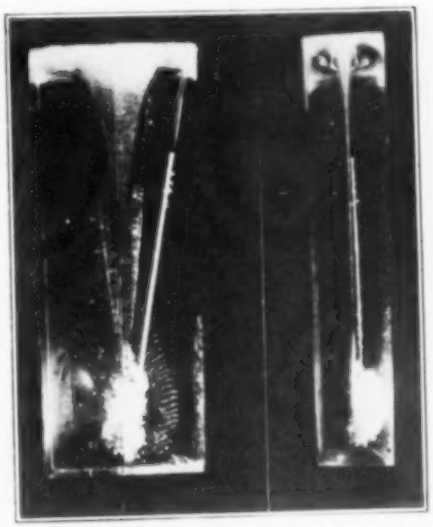
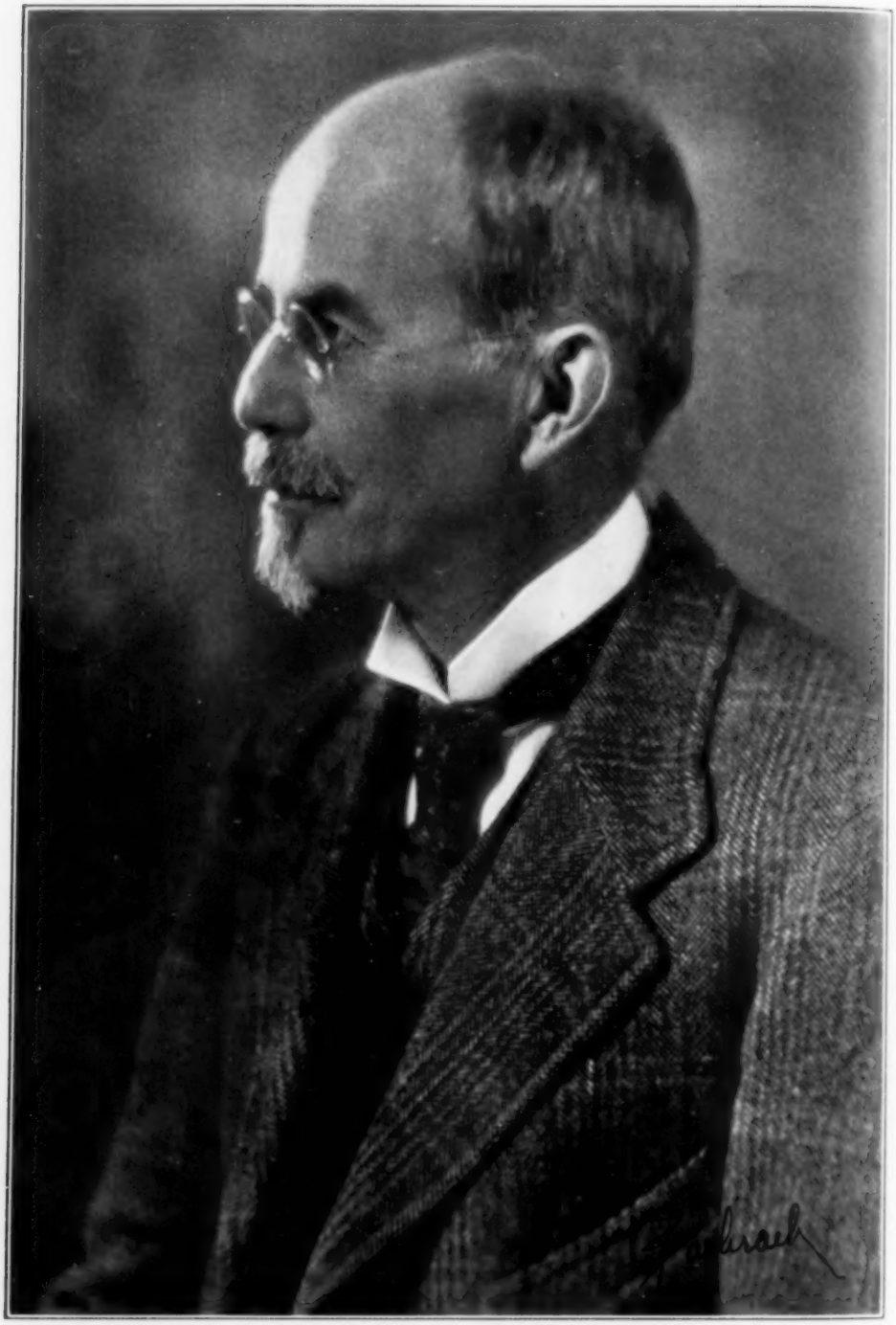


FIG. 7. ICE FROZEN FROM DISTILLED WATER

AGITATED BY MEANS OF AIR THROUGHOUT THE FREEZING OPERATION. OPACITY IN THIS CASE RESULTS FROM THE FACT THAT THE FINAL WATER WHICH FREEZES IS WHIPPED INTO AND FREEZES AS AN AIR FOAM, THE OPTICAL PROPERTIES OF WHICH DIFFER SUFFICIENTLY FROM THOSE OF ICE ALONE TO CAUSE LIGHT PASSING THROUGH THE ICE CAKE TO BE MATERIALLY SCATTERED.



PROFESSOR JOHN J. ABEL

PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE PROGRESS OF SCIENCE

PROFESSOR JOHN J. ABEL: PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE election to the presidency of an organization so thoroughly representative of the numerous branches of science as the American Association for the Advancement of Science is a public recognition that the person so honored is possessed of very high cultural and scientific qualifications and has made notable contributions in his chosen fields of interest. In electing Professor Abel as its president the association has not only conferred a well-merited honor on him, but it has also recognized him as a leader and distinguished contributor to science.

John Jacob Abel was born on May 19, 1857, and was brought up on a farm near Cleveland. As a child he showed a keen desire for learning and at the age of nineteen he entered the University of Michigan. He received his Ph.B. degree from this institution in 1883 after an interruption of three years, during which he taught Latin, mathematics, physics and chemistry at La Porte, Indiana. He then went to the Johns Hopkins University for a year of graduate study in physiology and biology.

That Professor Abel had the correct conception of the real nature and purpose of scientific medicine is evidenced by the fact that when, fifty years ago, he decided to make this his life work he was one of the very few medical men of his day who submitted himself to a long and thorough training in fundamental branches. From the fall of 1882 to January, 1891, when he was called to his alma mater (University of Michigan) as professor of materia medica and therapeutics (a title which is equivalent to that of professor of pharmacology) he spent nine years in intensive studies in physiology, chemistry, biochemistry, pharmacology and medicine in order properly to prepare himself as an investigator and teacher. Of this period one year was spent as a graduate student at the Johns Hopkins as already stated and six and a half years, from the summer of 1884 to January, 1891, in the Universities of Leipzig, Strassburg, Heidelberg, Berne and Vienna, with vacation studies in Würzburg, Berlin and Paris. Throughout these years, as I know from conversations with him, his mind was occupied with fundamental questions of a kind that must always underlie fruitful work in the biological and medical sciences. He chose to study under such great leaders as Carl Ludwig, Schmiedeberg, Hoppe-Seyler, Drechsel, von Nencki and Wislicenus in the fields of physiology, pharmacology, biochemistry and chemistry, and he enrolled himself as one of their pupils, both in the laboratory and in the lecture room. Then, too, the lectures and the ward rounds with famous clinicians, such as Strümpell, Wagner, Kussmaul and later Naunyn, not to forget Naunyn's associates, von Mering and Minkowski, Erb and Nothnagel and others aroused in him an interest in clinical medicine as taught by these men, who had themselves made important discoveries. The pathologists v. Recklinghausen and Arnold, neurologists of the older generation such as Meynert, great surgeons and many other leaders in the more special branches of medicine contributed to the broadening of outlook in the young man. In 1888 he took his examinations for the M.D. degree, in preference to the Ph.D. degree, at Strassburg, at that time a great German imperial university. The next two years he spent in graduate work at the University of Vienna and Berne, working at the latter university in the laboratory of the distinguished biochemist von Nencki, a pupil of Adolf Bayer.

In 1892, after two years as professor at the University of Michigan, Abel was called to the chair of pharmacology in the Johns Hopkins University, and he entered on his duties at the opening of the medical school here in 1893. As no professor of physiological chemistry had been appointed he was asked to give lectures and to supervise the laboratory work in that field, and for fifteen years thereafter the two departments—physiological chemistry and pharmacology—were both under his direction.

In the early years of the medical school some of Abel's work was of a purely biochemical character as, for example, his isolation of ethyl sulphide from among the products secreted by the dog's kidney and his study of the volatile mercaptans of the secretion of the common skunk. His familiarity with both stable and unstable aliphatic sulphur compounds of the animal organism bore fruit many years later, when in 1925 he and the writer were working on the purification of crude insulin extracts as guest research workers in the Gates Chemical Laboratory of the California Institute of Technology at Pasadena, California. Here Abel observed that all active fractions of insulin preparations contained labile sulphur in proportion to their blood-sugar lowering power, and this proved to be the clue which led to his subsequent successful crystallization of insulin.

Very early in his career he took up chemical and physiological studies of those important and elusive products of internal secretion, now known as hormones, of which "the race is both the beneficiary and the victim" (Barker). In 1895 he began work on the isolation of the extraordinary blood pressure raising hormone elaborated in the medullary portion of the suprarenal glands. A number of years were devoted to this problem with the result that the active principle was obtained in the form of a monobenzoyl derivative which Abel named epinephrine. Later Takamine obtained the free base, adrenaline, by omitting benzoylation, and precipitating out the base from very concentrated solutions with ammonia. Abel's early publications on his pioneer work in this field have been followed by thousands of papers by other investigators dealing with the physiological action, medical uses, chemical constitution and synthesis of this hormone. Years later (1911–1913) Abel came upon this compound again as a constituent of the creamy secretion of the skin glands of the large tropical toad, *Bufo Agua*. This toad not only produces epinephrine or adrenaline in its suprarenal organs, but has a large amount of this substance in its skin glands, amounting to 6 per cent. of the moist secretion. We have here the first example of an internal secretion or hormone which also appears as a protective poison in an external or skin secretion. After many previous workers had failed, Abel succeeded in isolating another crystalline compound, bufagin, from this toad skin secretion. It is a powerful heart stimulant, equally as powerful as and similar in action to the well-known digitalis.

With W. W. Ford from 1906 to 1908 researches were undertaken on the active principles of the poisonous mushroom, *Amanita phalloides*, known in French literature as "the destroying angel." Ford had shown in animal experiments that this fungus contains two separate principles of unknown character and composition, one a hemolysin and the other a non-hemolytic toxin. The hemolysin was isolated by Abel and Ford, although not in crystalline form, and found to be a nitrogenous sulphur-containing glucoside. The deadly constituent of the fungus, the toxin, was also isolated as a stable chemically indifferent compound containing both nitrogen and sulphur. This toxin accounts fully for the lethal character of this fungus

when ingested. The glucosidal constituent, Amanita-hemolysin, had previously been shown by Ford to have the properties of an antigen, that is to say, animals that had been prepared by small injections showed definite amounts of antihemolysin in their blood. These studies were also of importance, since both products, as isolated by Abel and Ford, were definitely shown not to be toxic albumins, as had been assumed by earlier investigators.

Another series of Abel's investigations lies in the field of chemotherapy. In conjunction with Rowntree studies were carried on from 1909 to 1910 on the efficacy of antimony thioglycolic acid compounds in the treatment of experimental trypanosomiasis. In this connection Abel prepared a new compound, the triamide of antimony thioglycolic acid, by an interesting synthesis. This compound, like sodium antimony thioglycolate, was found to be very effective in experimental trypanosomiasis and has now found a use in the treatment of the tropical disease known as *granuloma inguinale* and of Bilharzia.

Another line of work was undertaken in collaboration with Rowntree. Surgeons had called Abel's attention to their great need for a purgative that could be given after operations, especially laparotomies, by subcutaneous or intramuscular injection. Abel began studies of various phthalein derivatives with this point of view. The objective in this research was not attained, but findings of great value to medicine nevertheless resulted from these investigations. Abel and Rowntree found that phenolsulphonephthalein was excreted solely by the kidney, and since its introduction in 1910 into clinical medicine by Rowntree and Geraghty this agent has been used in many clinics as one of the most valuable tests for the functional power of the kidneys. The halogen substitution products of phenolphthalein—phenoltetrachlorphthalein and tetrabromphenoltetrachlorphthalein—were found to be excreted in the bile only, and this fact led to the development of tests for liver function by the use of these and similar compounds.

Then came the period of the researches on vividiffusion. Abel devised a simple apparatus and a method by which the blood from a living animal could be deflected from the body, passed through a dialyzing apparatus, and then returned to the body. In passing through the dialysis tubes of the apparatus the flowing blood rids itself of diffusible bodies of all kinds while retaining its blood corpuscles and large protein molecules. With this apparatus it was demonstrated for the first time by the free passage of amino acids through the membranes that these acids and also sugar, various oxyacids, some ferments, odoriferous constituents, as ethyl sulphide, and so on, exist in the blood in the free state and not in some firm combination, as say in peptide form, for amino acids, or, in some other form of union, as was suggested in the case of sugar. At least one new compound was isolated by Abel from the dialyzates of the blood of living dogs, namely, α-isobutylhydantoin ($C_7H_{12}N_2O$). The apparatus used in these vividiffusion experiments has often been referred to as an artificial kidney. Of course, it differs from a real kidney in exercising no selection in removing diffusible substances from the blood. It is, however, an easy matter to prevent the removal of any given substance, as, say, sugar, from the blood, by having an equal concentration of it in the saline on the outer side of the tubes. The apparatus has been used by many investigators for one purpose or another since it was first described, and the clinician Professor Georg Haas, of Giessen, has applied it with modified technique to human beings gravely ill

with glomerulo-nephritis; he has been able to alleviate their symptoms for five or six days at a time when their blood again accumulated the various organic principles that their diseased kidneys can not eliminate.

Among other fields of work coming within the range of Abel's scientific activity are the action of various dyestuffs in causing convulsions in frogs under various conditions, studies on the lymph hearts of frogs, studies in plasmaphaeresis, proof that proteoses exist in the free state in all the organs of the body as integral constituents of their cells or tissue spaces; that proteoses are not present in the blood in the free state, although they dialyze through membranes, but circulate as a compound or compounds of proteose and protein; that histamine is widely distributed throughout the organs of the body either as such but more probably in the form of a labile precursor; that the posterior lobe of the pituitary gland throws out its highly active constituents not as separate individuals but in the form of a unitary hormone. These researches which can be only alluded to here have given rise to an extensive literature often controversial in character.

One of Abel's major achievements remains to be described, namely, his separation and isolation in 1926 of the pancreatic hormone, insulin, as a beautifully crystalline compound from its admixture with proteins and other inert constituents in pancreatic extracts. It is characterized by a relatively high sulphur content and marked instability toward many chemical reagents and is destroyed by the ferments of the intestinal tract, and hence can not be administered by mouth. This is the first example of the isolation of an internal secretion product or hormone that must be classed with the proteins. It is another example among many of the production by one of our tissues of a powerful drug with quite specific actions; indispensable for health, but fatal in overdose, unless promptly antagonized by glucose. The true significance of this discovery, and the large amount of work that has followed from it in his laboratory as well as other laboratories can not be elaborated on here.

Not least among the contributions of Professor Abel to the advancement of the biological sciences is the founding of the *Journal of Biological Chemistry* with the late Dr. Christian A. Herter in 1905, and the *Journal of Pharmacology and Experimental Therapeutics* in 1909, which he still edits in association with Professor J. A. Gunn, of Oxford University in England.

Honorary degrees have been awarded Professor Abel by a number of leading universities in this country and in Europe. He has also been the recipient of several medals and prizes both here and abroad. He holds membership in many learned societies and honorary membership in seven foreign scientific societies and academies.

Professor Abel has a long list of pupils, many of whom hold professorships here and abroad and have attained distinction. A number of them have at one time or another during their period of apprenticeship assisted in carrying on the above researches, but always they have been urged to try their hand at problems of their own devising. Thus encouraged and supported by the master and spurred on by the example constantly before them of his own indomitable enthusiasm and unquenchable devotion to research, Professor Abel's many associates have made important contributions from his laboratory during the past forty years. Any one who will read his address on the "Education of the Superior Student" which appeared in the *Journal of Chemical Education* will find the secret of his influence on young men.

E. M. K. Geiling

THE SECOND NEW ORLEANS MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

To understand America without some personal acquaintance with the historic city of New Orleans is quite impossible. New Orleans is the least American of all our cities. It is exceptionally interesting for the picturesqueness of its older sections, and for the language, tastes and customs of a large portion of its people. It is as unique as the dark wet cypress forest draped with long pendent Spanish moss that once occupied its site, and which still encircles, more or less, its low horizon.

New Orleans is not so very old, but it has had a most romantic history. It was founded in 1718 by Jean Baptiste Lemoyne de Bienville, a French Canadian. A few years after its founding, when it was still a squalid village, it was made the capital of that vast Louisiana which vaguely included the entire Mississippi valley northward to Canada and extended westward no one knew how far.

In 1768, when the population had increased to about 3,200, the inhabitants of New Orleans and of the surrounding countryside mustered under arms almost to a man, refusing to accept the cession to Spain of Louisiana. By their show of unexpected force they compelled the holder of the Spanish king's commission to return to Havana. But in the following year Don Alexandro O'Reilly landed a formidable force of Spanish troops and took the city.

On November 30, 1803, the aged Spanish governor Salcedo handed the keys of the city back to the representatives of the French government. Twenty days afterwards, with similar ceremonies, the keys of the city passed from the hands of the French colonial prefect to those of the commissioners for the United States.

In this historic setting was held the eighty-ninth meeting of the association. And, strange to say, there was no disharmony between the meeting and the local background. For New Orleans has kept pace with modern progress. Energy and resourcefulness have created a thoroughly modern city able to hold its own with any other, yet at the same time constantly mindful of its romantic past.

Modern New Orleans was seen at its very best in everything connected with the meeting.

The local committee, under the guidance of Dr. Daniel S. Elliott, of Tulane University, carried out its work in the most thorough, energetic and efficient manner. It functioned throughout as a closely knit unit. Every problem that came before it was examined and analyzed and accorded its proper weight and place in the general scheme. In the earlier stages of its work the committee met once a week, later meeting oftener when necessary.

It is no exaggeration to say that as a result of the work of this committee the arrangements made to care for all the numerous divisions and subdivisions of the meeting were as nearly perfect as it was possible to make them. Many considered them quite perfect. All agreed that they were much superior to anything in the previous experience of the association.

The weather at New Orleans during the meeting seemed to have been planned as carefully as everything else. All the days were sunny, and all were summer-like, with a maximum temperature of 84°. About the open places in the city, especially about the Municipal Auditorium, and even in the busy city streets themselves there occasionally appeared conspicuous yellow butterflies, most unusual accompaniments of a winter meeting.

The entertainment program arranged by a special entertainment committee, of which Dr. Marten ten Hoor was chairman, was varied and most interesting.

THE PLACE D'ARMES

THE HEART OF OLD NEW ORLEANS, LAID OUT BY BIENVILLE IN 1718.

Many excursions were planned to places of interest both within and without the city. No American city offers so much that is unusual to the average American as New Orleans. The old French, Spanish and Creole quarter, known as the Vieux Carré, is especially attractive because of its Old World atmosphere, its narrow streets, its picturesque buildings, its galleries with their decorative wrought-iron railings and its beautiful courtyards. It is one of the few spots in the United States where international history has been made. It was in this quarter that the drama of the Spanish and French occupation, with its successive shifting of political, racial and cultural emphasis, was staged. In spite of the great changes that have occurred, the atmosphere of those days still remains. For this reason the Vieux Carré is today the favorite rendezvous of those painters, musicians and writers who either live in New Orleans or go there to spend the winter.

The country about New Orleans is as interesting and unusual as the city itself, and the trips to various places outside the city proved very popular. Every one who participated spoke very appreciatively of these excursions, which were well chosen and admirably conducted.

In addition to the out-of-doors excursions, a number of most delightful teas and other entertainments were arranged by the committee of hostesses, of which Mrs. A. B. Dinwiddie was chairman.

The attendance at the meeting was larger than had been expected. About 1,450 registered, but many attended who did not register. For instance, the meetings of the Wilson Ornithological Club averaged between 75 and 80 participants, none of whom registered. It is probably safe to say that the actual attendance was roughly double the registration figure.

The evening addresses proved very popular, the audiences numbering between 1,500 and 1,800 for each. Such a large attendance as this is quite exceptional and probably resulted, at least in part, from the advance distribution of about 12,000 tickets, and also from the closing of the exhibit in the same building just before each address.

The meeting was opened on Monday evening by the general chairman of the

GIBSON HALL

THE ADMINISTRATION BUILDING OF TULANE UNIVERSITY.

New Orleans Committee on Arrangements for the meeting, Dr. Daniel S. Elliott, of Tulane University. In a short address Dr. Elliott introduced Dr. Elmer D. Merrill who, in the absence of Professor Franz Boas, the president, and Dr. Bergen Davis, the senior vice-president, served as the presiding officer. Dr. Merrill introduced Dr. Robert A. Millikan, who responded to words of welcome by President A. B. Dinwiddie, of Tulane University, and by Dr. Frank R. Gomila, representing Mayor T. Semmes Walmsley, of New Orleans, and then presented the speaker of the evening, Dr. Richard P. Strong, of the Harvard University Medical School.

Dr. Strong outlined our present knowledge, in no small part the result of his own work, of various filarial "worms" which are responsible for certain distressing and often very serious ailments in tropical and subtropical regions. Following Dr. Strong's address there was a reception held in the Auditorium.

On Tuesday evening came the lecture of the Sigma Xi. This was given by Mr. C. F. Hirshfeld, of the Detroit Edison Company, who discussed the proper allocation of the responsibility for certain happenings and conditions in the affairs of men. Problems arising from the application of science to industrial life were treated from the point of view of an engineer who is engaged in the work of furthering applied science.

For Wednesday evening a program was arranged in memory of Thomas Alva Edison, who was one of the founders of the association's official organ *Science*. After an appreciation of Mr. Edison based on personal acquaintance by Dr. Charles L. Edgar, president of the Edison Electric Illuminating Company of Boston, there were two addresses on Edison's contributions to science and industry, one by Dr. Frank B. Jewett, vice-president of the American Telephone and Telegraph Company, and the other by Dr. Robert A. Millikan, director of the Norman Bridge Laboratory of Physics, California Institute of Technology. These addresses were followed by a description of Edison's laboratory in war time by Dr. Karl T. Compton, president of the Massachusetts Institute of Technology.

On Thursday evening many important problems connected with the control of the Mississippi River were discussed by Mr. Floyd A. Nagler, of the Iowa State University.

SCIENTIFIC EXHIBIT IN THE AUDITORIUM
WHICH ATTRACTED SOME 18,000 VISITORS.

The address on Friday evening was by Professor Irving Fisher, of Yale University, who discussed the causes of the present world depression, repeating the substance of his address in a radio talk immediately afterwards.

The scientific program was more extensive than had been anticipated. About 1,300 addresses and papers were presented—several hundred more than the number expected. The surprising thing about the papers, however, was not their number but their quality. The proportion of contributions, including material of unusual interest and value and written and delivered in a clear and lucid manner, was considerably greater than it has been at any meeting heretofore. The reason for this is not at first sight evident, and indeed is immaterial. For several years there has been noted a constant and continuous improvement in the programs. It would seem that the members are coming to the conclusion that the meetings of the association provide the best and most appropriate setting for the first announcement of new discoveries and new ideas.

A special feature of the meeting was the relatively large number of invited papers, covering a broad range of subjects, and particularly of invited papers arranged in symposia. Of these symposia the joint session of the physicists and mathematicians was perhaps the most noteworthy.

No other token of recognition of scientific merit in this country is of such widespread interest to the public as the annual award of the association's $1,000 prize for a noteworthy paper presented at the meeting. At the New Orleans meeting this prize was awarded to Dr. Carl Caskey Speidel, of the University of Virginia Medical School, for his paper on "Studies of Living Nerves. II. Activities of Ameboid Growth Cones, Sheath Cells, and Myelin Segments, as Revealed by Prolonged Observations of Individual Fibers in Frog Tadpoles."

Dr. Speidel's paper was remarkable not only for its unusually high scientific value, but also for simplicity and clarity of expression. He knew exactly what he wished to say and said it in a way that any one with a reasonable education and some knowledge of biology could understand. It was received by the Press Service well in advance of the

meeting. So important did it seem to the press representatives that it was mentioned as a leading contribution to the scientific program of the meeting in Tuesday afternoon and Wednesday morning papers.

It is a real pleasure to be able to say that Dr. Speidel's long-continued, painstaking and brilliant work was appraised at its true value both by his scientific colleagues and by those who interpret our meetings for the benefit of the public at large.

A scientific meeting would be sadly incomplete if the participants confined themselves to imparting information through the ear alone. Many people prefer to acquire information through the eye, or at least are not quite satisfied unless both ear and eye receive their share.

One of the most distinctive features of the New Orleans meeting was the extraordinary series of scientific exhibits brought together through the efforts of a special committee, of which Dr. Fay C. Brown was chairman and Mr. Owen Cattell was secretary.

These exhibits were so very diversified that every one, no matter in what field his interests lay, found something fascinating. There was a collection of copies of documents relating to the Louisiana purchase, a demonstration of the physiological changes that occur with fatigue, a booth showing the beaver at home, a special depicting of the Federal government's potash exploration in Texas and New Mexico, a display of living plants demonstrating the importance of both heredity and environment in molding the organism, a demonstration of the light-sensitive Geiger counter, and a mechanical hen. And there were very many other exhibits equally interesting.

The adequate display of these exhibits was made possible through the courteous and generous action of the City of New Orleans, which provided free of all charge space in the Municipal Auditorium having a rental value of $3,250.

The organizations that furnished these exhibits were: The Department of State; the Treasury Department (Public Health Service); the Navy Department (Naval Research Laboratory); the Department of the Interior (Geological Survey); the Department of Agriculture (Bureau of Entomology, Bureau of Animal Husbandry, Biological Survey, Bureau of Home Economics, Bureau of Chemistry and Soils, U. S. Forest Products Laboratory and Information Office); Department of Commerce (Coast and Geodetic Survey, Bureau of Fisheries, Bureau of Standards and Bureau of Mines); the U. S. Waterways Experiment Station at Vicksburg, Miss.; the Carnegie Institution of Washington (Department of Eugenics, Division of Historical Research, Division of Plant Biology, Moon Committee and Geophysical Laboratory); Tulane University; Louisiana State University; Columbia University; Johns Hopkins University; University of Illinois; Rutgers University; Fordham University; University of Oklahoma; George Washington University; Rice Institute; American Museum of Natural History; New York Museum of Science and Industry; Blodgett Memorial Hospital; New York Botanic Garden; Aeronautical Chamber of Commerce; The Century of Progress (Chicago); Society of American Foresters; Botanical Society of New Orleans; New Orleans Chapter of the Nature Study Society; Science Club of the Morris High School, the Bronx, New York; Society of Petroleum Geologists; Association of Edison Illuminating Companies; Thomas Alva Edison Memorial Exhibit; E. I. du Pont de Nemours and Company; American Steel and Wire Company; and the Leeds and Northrup Company.

The exhibits collectively afforded a wonderful cross section of the achievements and the mysteries of modern science. A study of the exhibits furnished of itself alone a liberal education in the fundamentals of modern science.

It was estimated by those in charge that about 18,000 visited the exhibition hall, demonstrating in the most effective manner that the exhibits were appreciated by the people of New Orleans. In a letter to the exhibitors written after the meeting Dr. D. S. Elliott, the chairman of the local committee, said: "We of New Orleans and Tulane feel that you have helped to sensitize our community to the achievements and potentialities of science, and it is our opinion that you have rendered a splendid service to science . . ."

Quite as interesting and diversified as the non-commercial exhibit was the commercial exhibit assembled by Colonel H. S. Kimberly and displayed in the Venetian Room of the Roosevelt Hotel. Sixteen firms, including dealers in all types of laboratory and class-room equipment, books, filing cabinets and biological supplies and specimens, cooperated in this exhibit. Much of the laboratory equipment shown was new, and a number of appliances were here demonstrated for the first time.

The exhibits serve a most useful purpose in illustrating in a broad and general manner the association's program. As we look back on former years it is difficult to understand how we ever got along without them.

The program is one thing, the local background quite another. Most important is the setting by means of which the meeting, of which the nucleus is the program, is made to harmonize with the background.

Nothing is self-accomplished. A harmonious meeting is the tangible result of well-directed, unremitting, more or less thankless work.

The association appreciates most keenly the unusually efficient and effective manner in which the local committee carried out its work, and tenders them its sincere and cordial thanks for a most unusual and successful meeting.

AUSTIN H. CLARK

ROBERT DeCOURCY WARD

ROBERT DECOURCY WARD was born in Boston on the 29th of November, 1867, and died in Cambridge on the 12th of November, 1931. He was the son of Henry Veazey and Anna Saltonstall (Merrill) Ward. Henry Ward, the father, spent much of his business life in Valparaiso, Chili, with the firm of commission merchants, Frederick Huth and Company of London. On retiring he came to live in Boston, then was appointed consul from Chili at the court of Saxony. For this reason Robert was taken to Dresden when six months old, remained there four years, then a year in Lausanne, where his father died, a year in England and returned to Boston in 1874. He attended Boston schools, preparing for Harvard at Noble's School. Entering college he graduated in 1889, *summa cum laude*. In his junior year he became interested in studies of the atmosphere through courses taken with Professor Wm. M. Davis.

After graduating he spent a year in Europe, and returning in the autumn of 1890, became an assistant in geography and meteorology at Harvard. Later he became instructor, assistant professor and in 1910 professor of climatology. He was the first one to hold such a chair in America.

In 1897 he married Miss Emma Lane, of Saint Louis, who, with two sons and two daughters, also two sisters, survive him.

Ward had an intense interest in teaching and as a pioneer in his field did an immense amount to bring together and assimilate the knowledge of his subject and put it in form for class instruction. Constantly revising his lectures and laboratory work he ever strove to give his students the essential principles of the subject and the fullest and latest information possible.

He was a great believer in field work, and to gather first-hand knowledge of his subject traveled extensively. He

ROBERT DECOURCY WARD

LATE PROFESSOR OF CLIMATOLOGY IN HARVARD UNIVERSITY.

was fond of the sea and in his younger days made many trips to Europe; he went to South America three times, visited the West Indies, traveled in this country, and in 1929 went around the world.

Besides his teaching, which he kept up with most painstaking care, both in Harvard College and in Radcliffe, he did an immense amount of administrative work. He was on the administrative board of Harvard College for over thirty years, chairman of the board of freshman advisers for many years, also for several years chairman of the department of geology and geography. In addition he was at times a member of other faculty committees. Too much to require of a man, but he liked the work and did it with painstaking care and good judgment.

Outside of his active professional career he was deeply interested in safeguarding the country from unlimited immigration. From the early nineties he instituted and kept up by writing and interviewing an active effort to awaken and educate the American public on this important matter in which he became a recognized authority. With the late Prescott F. Hall, in 1894, he founded the Immigration Restriction League, the first organization of its kind in America. For over thirty years he was a member of the executive committee, part of the time chairman or president of the league. This interest his son Henry is carrying on.

Besides his teaching, administrative and immigration work he did a large amount of writing. He published "Practical Exercises in Elementary Meteorology," 1899; "Climate Considered Especially in Relation to Man," 1908, with a second edition, 1918; "The Climate of the United States," 1925; "Handbook of Climatology," 1903, a translation of the first volume of Hann's "Handbuch der Klimatologie." Besides these, which are accepted as standard books to-day, he published over 300 longer or shorter papers, and in addition numerous notes or reviews on topics connected with his work. His writing was always clear and concise, and is a remarkable proof of his diligence and ability. Everything that he did he did well and his publications are accepted by men competent to judge as those of a master in his subject. Readers of THE SCIENTIFIC MONTHLY will appreciate the great value of the numerous articles contributed by him to the magazine.

The death of Robert DeCourcy Ward takes a man eminent in his chosen profession and of exceptional nobility of character. Painstaking, careful, accurate in his work, whether teaching, writing or administrative, there was nothing loose or careless in his attitude. He was always to the point. Of a sensitive, nervous, highstrung temperament, he so planned his time that he accomplished an extraordinary amount of work. Liberally generous with others, he was exacting with himself and unsparing in devoted service to the university and to public affairs, in which he took so keen an interest.

He was always interested in the practical application of his subject, climatology, to human affairs. A cultivated gentleman, with a gentleman's point of view, simple, unassuming, he was an example of what is best in a university man. As Dean Briggs said to me, "There was nothing finer than Ward anywhere." His going will make a great gap and many a sad heart.

It was my privilege to know Ward intimately, having been in his department at Harvard for many years, and also for years his next-door neighbor in Cambridge. His loyalty and devotion to his friends was an essential part of his life. His sense of what is right was of the highest order, and I have known him to do things very hard to do because of his keen sense of rectitude. His fine, upright character, his loyalty and his sense of justice were an influence on all about him and will be an inspiring and beautiful memory to his friends.

ROBERT TRACY JACKSON